RECENT DEVELOPMENTS IN PHYSICS EDUCATION IN CANADA

FAITS NOUVEAUX DANS L’ENSEIGNEMENT DE LA PHYSIQUE AU CANADA
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A “Flipped” Approach to Large-Scale First-Year Physics Labs, by Georg W. Rieger, Michael Sitwell, James Carolan and Ido Roll

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FOREWORD

RECENT DEVELOPMENTS IN PHYSICS EDUCATION IN CANADA

Work in physics education can take many forms. Some is research-based, such as the modeling of students’ conceptual understanding and cognitive processes. Some work focuses on designing and developing best instructional practices (pedagogies, curricular materials, laboratory activities). Some focuses on the preparation of future teachers or outreach activities for the public. Attention to physics education helps sustain healthy undergraduate and graduate enrollment in physics programs and helps prepare – and maintain - a vibrant community of professional physicists in academe and industry. In this special issue, we showcase some recent developments in physics education since the previous update 5 years ago[1].

In this Foreword we present an overview of physics education in Canada, including papers on Physics Education Research (PER), best teaching practices and teacher preparation.

There is a clear and growing interest in physics education among Canadian Physicists. While the overall membership in CAP has been static, membership in the Division of Physics Education (DPE) has grown by more than 50% in less than 10 years. The DPE sessions at the CAP congress are normally held in the larger halls and often overflow the capacity of the room. There were only two DPE sessions at the 2005 congress. In 2013 there were 5 regular sessions plus a joint session with CEWIP. These are in addition to the special plenary talk given by the recipient of the CAP medal for excellence in teaching. In the last several years, the CAP Congress featured invited talks with high-profile speakers like Nobel Laureate Carl Wieman who has turned his attention to improving Physics/Science education. While Wieman gave the Herzberg Memorial Lecture at the 2007 CAP Congress in Saskatoon, Harvard professor Eric Mazur - the father of Peer Instruction - delivered a plenary talk at the 2008 Congress in Quebec City. Last year, a plenary talk was given by Edward (Joe) Redish, an internationally recognized PER scholar and the founding director of the renowned PER group at the University of Maryland.

Within this context of interest and growth of physics education in Canada, the editor of Physics in Canada (Béla Joos) and of its education corner (Rob Thompson, winner of the 2007 CAP Medal for Excellence in Teaching Undergraduate Physics) suggested this special issue at the 2013 CAP Congress meeting of DPE. The objective is not to provide a set of papers that paint an exhaustive picture of Physics Education in Canada. Each paper in this issue presents a brief sampling of interesting work done in different institutions across the country. We simply provide a snapshot of a select number of recent developments in Physics Education in Canada. We received a total of 25 proposals. All articles were refereed by at least two reviewers. Ultimately we selected 20 articles for publication covering the following areas:

PHYSICS EDUCATION RESEARCH (PER) IN CANADA

The field of PER in Canada is relatively new and growing. Doctoral programs in PER are found at the University of British Columbia, the University of Calgary and Concordia University in Montreal. We also received articles in PER outside of these institutions that indicate a widespread interest in the field. While these are particular examples of initiatives sampled across Canada, at the same time they represent emerging trends and show the direction in which Canadian PER is going.

In a paper by Harlow et al., students’ attitudes about science are explored in conjunction with the breadth of courses and students’ interactive engagement. They find that student engagement positively shapes their attitudes and views on the nature of science. An interesting PER study is presented by Williams et al. and assesses whether students interacting during peer-instruction activities respond to peer-pressure. They find that the combined effect of random guessing and students who voted but did not participate in the peer interaction process was substantial. In another quantitative PER study, Harrison (winner of the 2012 CAP Medal for Excellence in Teaching Undergraduate Physics) quantifies the uncertainties associated with final grades in physics courses.
and finds that they are at least 4% and probably much larger. A paper by Wang and Kalman (winner of the 1999 CAP Medal for Excellence in Teaching Undergraduate Physics), describes how to improve students’ understanding of physics. They describe how students’ beliefs about the nature of knowledge and knowing (i.e., epistemic beliefs) in physics have important effects on how they learn physics. They go on to describe three learning activities that were designed to advance students’ epistemic beliefs. Day et al. consider how a good invention activity should present a readily interpretable goal and engaging scenario to the student. Holmes examines the well-studied notion that women are under-represented in the physical sciences. Finally two graduate students Khanam (Concordia university) and Sobhanzadeh (University of Calgary) focus on using reflective writing activity and laboratory exercises to help students understand the scientific conceptions covered in introductory physics courses.

IMPLEMENTING PHYSICS EDUCATION RESEARCH-INFORMED PEDAGOGIES

An interesting implementation of a studio-physics program for grades 11 and 12 is carefully described and thoroughly documented by York Mills High School teacher Meyer. Many of the large learning gains documented in the PER literature are replicated and at times even surpassed. Whittaker (a 2013 winner of the CAP teaching prize for High School and CEGEP teaching) and Charles describe in another paper how research can inform classroom design. The paper builds on research findings showing that the central focus in classrooms should not be on the teacher but students and their social interactions (include peer-to-peer interactions and novice-to-expert interactions). In another paper by Charles et al., the construction of a community of practice composed of post-secondary science instructors is described. The aim of the resulting SALTISE consortium is to support the implementation of pedagogical innovations. Aligned with the idea of implementing and replicating pedagogical innovations and making them sustainable and lasting, this issue features a number of papers that document the implementation of PER-informed pedagogies in various contexts.

PREPARING FUTURE PHYSICS TEACHERS

Two articles describe a growing focus on the preparation of future physics teachers. In a paper by Milner-Bolotin (winner of the 2010 CAP Medal for Excellence in Teaching Undergraduate Physics), a course aimed at future physics teachers brought PER results into the classroom and challenged future teachers to design PER-informed conceptual resources for physics teaching. In another article on the preparation of future physics teachers, Bullock describes his attempt to help future physics teachers develop strategies for using PER findings in their future work as secondary school teachers.

PHYSICS OUTREACH IN CANADA

An example of outreach initiative is provided by Bluteau and Barkanova. The paper describes an initiative to share Bluteau’s experience as a student participating in a honours summer research program at CERN. When he returned, Bluteau delivered outreach presentations at local Nova Scotia high schools about his time at CERN, particle physics, and physics as a career option. The authors argue in favor of the student-driven, students-delivered outreach.

ACTIVE LEARNING AND ENGAGING STUDENTS

A great deal of attention has been paid in recent years to reforming introductory physics classes, while innovations in the upper division courses are still long overdue. Hawkes (winner of the 2000 CAP Medal for Excellence in Teaching Undergraduate Physics) focuses on the implementation of the original seven principles of effective undergraduate education at the upper level undergraduate physics courses. The paper argues in favor of designing upper level physics courses that more faithfully replicate the work of professional physicists.

At the undergraduate level, there is often sizable overlap between introductory physics and calculus. In a paper by O’Meara (winner of the 2011 CAP Medal for Excellence in Teaching Undergraduate Physics) et al., a new course is described where Mathematics and Physics are now being taught in an integrated fashion that demonstrates how they support and enrich one another. This initiative is an exciting opportunity to enhance first-year science education and stimulate growth in existing programs.

The shift towards more formative assessments is a trend in today’s education. An article by Ives on quizzes as learning experiences provides an example of this trend. His article describes a weekly quiz implementation which incorporates peer interactions in the form of follow-up collaborative group quizzes, and additional formative assessment through post-quiz reflection assignments.

Technology can bring new opportunities to the classroom. Using videos and video analysis for physics teaching is still relatively new in Canada, although it is quickly gaining popularity. The article by Lenton and Adams discusses student-generated videos and their role in the physics classroom. They describe how two distinct video creation activities (videos analyzing real-world motion and videos explaining physics concepts) help to engage students in active learning in their institution.

OTHER INITIATIVES

Michal considers a set of lab activities based upon the hardware and physics of magnetic resonance imaging, while Adams and Chen consider using studies in photonic-related fields in a waves for modern physics course. Rieger et al.
consider having students perform some experiments at home and bring the data to class for discussion and analysis.

Growth in the Canadian economy requires a cadre of technically trained personnel. Mathematics and science education throughout the country needs to be improved dramatically if Canada wants to remain competitive in the 21st century. Canadian students do not perform badly in international comparisons of mathematics and science reasoning, but their ranking has slipped\(^2,\ 3\).

Students dropping out of physics courses is a loss that must be stemmed. We conjecture that if we pay more attention to improving physics education, then we can expect more success in the understanding of the subject by our students, which in turn should result in scientific research by future graduate students that would advance the Canadian economy.

We hope you enjoy finding some ways to improve your own classrooms as you read through the following articles. Sincere thanks to all authors for their contributions.

Tetyana Antimirova, Ryerson University
Calvin Kalman, Concordia University
Nathaniel Lasry, John Abbott College
Guest Editors, Physics in Canada

Comments of readers on this foreword are more than welcome.

REFERENCES

FAITS NOUVEAUX DANS L’ENSEIGNEMENT DE LA PHYSIQUE AU CANADA

Un travail sur l’enseignement de la physique peut prendre bien des formes. Il est parfois axé sur la recherche, comme le modélage de la compréhension conceptuelle et des processus cognitifs chez les étudiants. Il vise aussi à concevoir et à élaborer de meilleures méthodes d’enseignement (pédagogie, matière exposée, activités en laboratoire). Il peut également viser à préparer les futurs enseignants ou des activités de liaison avec le public. Le soin porté à l’enseignement de la physique aide à maintenir de bons taux d’inscription aux programmes de physique du premier cycle et des cycles supérieurs ainsi qu’à préparer – et à maintenir – une collectivité dynamique de physiciens professionnels dans le monde universitaire et l’industrie. Ce numéro spécial présente certains faits nouveaux dans l’enseignement de la physique depuis la mise à jour précédente, il y a cinq ans\(^1\). Cette Préface fournit un aperçu de cette discipline au Canada, en présentant des articles sur la recherche en enseignement de la physique (REP), les meilleures méthodes à cette fin et la préparation des enseignants.


Dans ce contexte d’intérêt et d’essor de l’enseignement de la physique au Canada, le rédacteur en chef de La Physique au Canada
(Béla Joós) et de la chronique « La physique et l’éducation » (Rob Thompson, lauréat de la Médaille de l’ACP 2007 pour l’excellence en enseignement de la physique au premier cycle) a proposé ce numéro spécial lors de la réunion de la DEP au congrès de l’ACP 2013. L’idée n’est pas de fournir une série d’articles donnant une image complète de cette discipline au Canada. Chaque article de ce numéro décrit brièvement des travaux intéressants qui se font dans divers établissements à travers le pays. Nous prenons simplement un instantané de divers faits bien étudiés selon laquelle les femmes sont sous-représentées en sciences physiques. Enfin, deux étudiants des cycles supérieurs, Khanam (Université Concordia) et Sobhanzadeh (Université de Calgary), se penchent sur l’utilisation d’activités de rédaction réfléchie et d’exercices en laboratoire pour aider les étudiants à comprendre les conceptions scientifiques scrutées dans les cours d’introduction à la physique.

MISE EN ŒUVRE DE PÉDAGOGIES AXÉES SUR LA RECHERCHE EN ENSEIGNEMENT DE LA PHYSIQUE

La mise en œuvre intéressante d’un programme de physique en studio pour la 11e et la 12e année est décrite avec soin et documentée à fond par le professeur Meyer de l’école secondaire York Mills. Nombre des gains d’apprentissage importants décrits dans les articles sur la REP sont reproduits et parfois même surpassés. Whittaker (lauréat 2013 du prix de l’ACP en enseignement au secondaire et au CÉGEP) et Charles décrivent dans un autre article comment la recherche peut influer la conception des cours. L’article mise sur les résultats de la recherche, montrant que le centre d’intérêt en classe ne devrait pas être le professeur mais les étudiants et leurs interactions sociales (englobe l’interaction entre les pairs et entre novices et experts). Un autre article par Charles et autres décrit la mise en place d’une communauté de pratique composée d’enseignants en sciences au postsecondaire. L’objectif du consortium SALTISE, qui en émane, est d’appuyer la mise en œuvre d’innovations pédagogiques. Outre l’idée de mettre en œuvre et de reproduire les innovations pédagogiques ainsi que de les rendre soutenables et durables, ce numéro présente un certain nombre d’articles qui illustrent la mise en œuvre de pédagogies axées sur la REP en divers contextes.

PRÉPARER DE FUTURS ENSEIGNANTS EN PHYSIQUE

Deux articles décrivent un intérêt croissant pour la préparation des futurs enseignants en physique. Dans celui de Milner-Bolotin (lauréate de la Médaille de l’ACP 2010 pour l’excellence en enseignement de la physique au premier cycle), un cours pour futurs enseignants en physique communique les résultats de REP en classe et les met au défi de concevoir, pour l’enseignement de cette discipline, des ressources conceptuelles axées sur la REP. Dans un autre article sur la préparation des futurs enseignants en physique, Bullock décrit sa tentative en vue de les aider à élaborer des stratégies permettant d’utiliser les résultats de la REP dans leur futur travail à titre d’enseignants au secondaire.

LE RAYONNEMENT DE LA PHYSIQUE AU CANADA

Bluteau et Barkanova citent un exemple d’initiative de rayonnement. L’article décrit une initiative visant à partager l’expérience de Bluteau à titre d’étudiant inscrit à un programme estival de bourses de recherche au CERN. À son retour, Bluteau a fait des exposés de promotion de la physique dans les écoles.
secondaires de Nouvelle-Écosse au sujet de son temps passé au CERN, de la physique des particules et de cette discipline à titre de choix de carrière. Les auteurs se disent favorables à une promotion axée sur les étudiants et émanant d’eux.

L’APPRENTISSAGE ACTIF ET L’ENGAGEMENT DES ÉTUDIANTS

Ces dernières années, on a fait grand cas de la réforme des cours d’introduction à la physique, tandis que les innovations aux cours de niveaux supérieurs demeurent attendues depuis longtemps. Hawkes (lauréat de la Médaille de l’ACP 2000 pour l’excellence en enseignement de la physique au premier cycle) met l’accent sur la mise en œuvre des sept principes initiaux de l’enseignement efficace au premier cycle de cours de physique au niveau supérieur. L’auteur favorise la conception de cours de physique de niveau supérieur qui reproduisent plus fidèlement le travail de physiciens professionnels.

Au niveau du premier cycle, il y a souvent un chevauchement sensible entre l’introduction à la physique et le calcul. L’article d’O’Meara (laureate de la Médaille de l’ACP 2011 pour l’excellence en enseignement de la physique au premier cycle) et autres décrit un nouveau cours où les mathématiques et la physique sont maintenant enseignées d’une façon intégrée qui montre qu’elles s’appuient et s’enrichissent mutuellement. Cette initiative est une excellente occasion d’améliorer l’enseignement des sciences en première année et de stimuler la croissance des programmes en place.

L’enseignement d’aujourd’hui dénote une tendance à évoluer vers des évaluations plus formatives. Dans un article sur les jeux-questionnaires à titre d’expériences d’apprentissage, Ives illustre cette tendance. Il décrit la tenue hebdomadaire d’un jeu-questionnaire alliant l’interaction entre des pairs dans des jeux-questionnaires de suivi de groupes de collaboration, et d’autres évaluations formatives par des exercices de réflexion à la suite des jeux-questionnaires.

La technologie peut offrir de nouvelles possibilités en classe. L’utilisation et l’analyse de vidéos pour l’enseignement de la physique sont encore relativement nouvelles au Canada, bien qu’elles gagnent rapidement en popularité. Dans leur article, Lenton et Adams traitent de vidéos produites par des étudiants et de leur rôle en classe de physique. Ils décrivent comment deux activités distinctes de création de vidéos (analysant le mouvement dans le monde réel et expliquant des concepts de physique) aident à engager les étudiants à l’apprentissage actif au sein de leur établissement.

AUTRES INITIATIVES

Michel examine une série d’activités en laboratoire en se fondant sur le matériel et la physique de l’imagerie par résonance magnétique, tandis qu’Adams et Chen scrutent l’utilisation d’études dans les domaines liés à la photonique dans une vague de cours de physique moderne. Rieger et autres scrutent la possibilité que les étudiants fassent des expériences à la maison et ramènent les données en classe aux fins de discussion et d’analyse.

La croissance de l’économie canadienne requiert un effectif ayant une formation technique. L’enseignement des mathématiques et des sciences dans l’ensemble du pays doit être amélioré radicalement si le Canada veut demeurer compétitif au 21e siècle. Les étudiants canadiens se situent assez bien dans les comparaisons internationales en raisonnement mathématique et scientifique, mais ils ont perdu du terrain.

Le décrochage des étudiants aux cours de physique est un recul qu’il faut endiguer. Nous croyons que, si nous veillons davantage à améliorer l’enseignement de la physique, nous pourrons alors espérer une meilleure compréhension du sujet par nos étudiants, ce qui devrait amener en revanche les futurs étudiants des cycles supérieurs à mener des recherches scientifiques capables de faire progresser l’économie canadienne.

Nous espérons que vous apprécierez de découvrir des moyens d’améliorer vos propres cours par la lecture des articles suivants. Nos remerciements sincères à tous les auteurs pour leur apport.

Tetyana Antimirova, Ryerson University
Calvin Kalman, Concordia University
Nathaniel Lasry, CEGEP John Abbott
Rédaiteurs honoraires, La Physique au Canada

Les commentaires de nos lecteurs (ou lectrices) au sujet de cette préface sont bienvenus.

NOTE: Le genre masculin n’a été utilisé que pour alléger le texte.

RÉFÉRENCES

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<td>Bela Joos</td>
<td>J. Michael Pearson</td>
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<tr>
<td>Nicolas Doiron-Leyraud</td>
<td>James King</td>
<td>Waldemar A. Priezkonka</td>
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<td>Gordon Drake</td>
<td>Christine Kraus</td>
<td>David Poulin</td>
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<td>Giovanni Fanchini</td>
<td>R.M. Lees</td>
<td>Klaus E. Rieckhoff</td>
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<td>Robert Fedosejevs</td>
<td>Robert Mann</td>
<td>Robert G.H. Robertson</td>
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<td>Henry R. Glyde</td>
<td>Louis Marchildon</td>
<td>Pierre Savard</td>
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**CAP**

**PHYSICS IN CANADA**

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Physics and Education

The Effects of Physics Breadth Courses on Student Attitudes About Science

by Jason J.B. Harlow, Rikki Landau, and David C. Bailey

At the University of Toronto (U of T), students must specialize in one or more disciplines and take a small number of courses outside their areas of specialization. So-called “breadth courses” serve to expose students to areas of knowledge and critical methods outside their primary area of study. Physics breadth courses give students pursuing non-science degrees insight into how physicists think and approach problems. While instructors aim to increase our students’ knowledge of physics facts and concepts, a more fundamental goal is to cultivate a long-lasting appreciation of evidence-based methods of inquiry. Yet our assessment methods rarely probe student attitudes; these methods tend to test accumulation of knowledge and mathematical abilities.

Survey Methods

The CLASS survey[1] asks students to respond to 42 statements on a five point scale from A: ‘strongly disagree’ to E: ‘strongly agree’. When physicists answer, 36 of the statements elicit strong consensuses. Student responses to these 36 statements can be scored to quantify how expert-like or novice-like their attitudes are. Between fall 2003 and fall 2005, the creators of CLASS administered the survey to over 7000 students in 60 different physics courses. Based on the results, they developed eight empirically determined, non-mutually-exclusive categories: “Personal Interest” (PI), “Real-World Connections” (RWC), “Problem Solving General” (PWG), “Problem Solving Confidence” (PSC), “Problem Solving Sophistication” (PSS), “Sense Making and/or Effort” (SME), “Conceptual Connections” (CC) and “Applied Conceptual Understanding” (ACU).

We attempted to measure student attitudes using CLASS in two different physics breadth courses at U of T: (1) PHY100 “The Magic of Physics”, in which we surveyed 234 students over the spring and summer of 2013, and (2) PHY205 “Physics of Everyday Life” in which we surveyed 461 over the spring and summer of 2013. PHY100 explored a range of introductory physics topics, with traditional lectures and tutorials that involved minimal formal student participation. PHY205 was taught by one of us (JBH), and every class clicker remotes were used in lectures to promote in-class discussions. Every week students worked in teams of 3 in tutorials to make measurements and observations using simple laboratory equipment.

We administered CLASS in the first and last weeks of each semester to obtain the pre and post-course scores. We asked students about their backgrounds, and offered students no marks incentives for participating. Of 695 enrolled students, 414 wrote the pre-course survey, 470 wrote the post-course survey, and 330 wrote both. The average final mark of students who wrote both surveys was 77%, while the average final mark of the 143 students who wrote neither survey was 62%. Since surveys were done on paper during tutorials, lower marks may be attributable to students who tend to skip tutorials.

Although students responded to the CLASS statements on a five point scale, we analyzed the survey data on a two point scale, in line with other researchers using CLASS[2-4]. For each of the 18 statements with which experts tend to agree, we counted ‘agree’ and ‘strongly agree’ as favourable responses. For each of the 18 statements with which experts tend to disagree, we counted ‘disagree’ and ‘strongly disagree’ as favourable. We did not score the 5 statements for which CLASS researchers found no strong expert agreement, nor a control statement used to identify students who may be choosing random answers.

Summary

We administered the Colorado Learning Attitudes About Science Survey (CLASS) at the beginning and end of four physics breadth courses, and found a slight improvement in CLASS scores when interactive teaching methods were used, as well as a difference in CLASS scores and gain for students with different high school physics backgrounds.

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The Effects of Physics Breadth Courses on Student Attitudes... (Harlow et al.)

TABLE 1

Comparison of pre- and post- CLASS results for the two breadth courses of this study. Average percentage of favourable responses is shown, with standard error of the mean in parentheses. Shifts that are statistically significant at the $p < 0.05$ level are shown in bold.

<table>
<thead>
<tr>
<th>CLASS category</th>
<th>PHY100 (N = 93)</th>
<th>PHY205 (N = 237)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre (N = 93)</td>
<td>Post (N = 93)</td>
</tr>
<tr>
<td>Overall</td>
<td>57.4 (1.6)</td>
<td>56.5 (1.9)</td>
</tr>
<tr>
<td>Personal Interest</td>
<td>60.8 (2.7)</td>
<td>64.2 (3.4)</td>
</tr>
<tr>
<td>Real World Connections</td>
<td>73.7 (2.7)</td>
<td>72.6 (3.1)</td>
</tr>
<tr>
<td>Problem Solving General</td>
<td>61.2 (2.7)</td>
<td>61.7 (2.7)</td>
</tr>
<tr>
<td>Problem Solving Confidence</td>
<td>59.4 (3.4)</td>
<td>59.4 (3.2)</td>
</tr>
<tr>
<td>Problem Solving Sophistication</td>
<td>45.7 (3.0)</td>
<td>45.5 (3.1)</td>
</tr>
<tr>
<td>Sense Making and/or Effort</td>
<td>68.8 (2.2)</td>
<td>64.2 (2.5)</td>
</tr>
<tr>
<td>Conceptual Connections</td>
<td>54.3 (2.6)</td>
<td>51.4 (2.9)</td>
</tr>
<tr>
<td>Applied Concept Understanding</td>
<td>40.9 (2.2)</td>
<td>39.2 (2.6)</td>
</tr>
</tbody>
</table>

RESULTS

Table 1 shows the average percentage of favourable responses, both overall and for the eight specific categories, for all 330 students who wrote both the pre- and post-course surveys.

Lack of Significant Decrease in Favourable Attitudes

Some studies have shown a significant decline in the percentage of favourable responses after taking introductory physics courses[13]. In our study, PHY100, with its traditional lectures and tutorials, resulted in a slight downward shift in overall CLASS score of $-0.9 \pm 1.6\%$ over one semester. PHY205, which incorporated a more interactive teaching style in lectures, and a more hands-on approach in tutorials, produced a slight upward shift in overall CLASS scores of $+1.7 \pm 0.9\%$.

In PHY205, for the Problem Solving Confidence (PSC) category, we saw a statistically significant increase in percentage favourable responses from $60.9 \pm 2.0\%$ up to $66.8 \pm 2.0\%$, which is a $+2.8\sigma$ gain over the semester. The paired $t$ test shows the probability of the pre- and post- scores being the same for the PSC category is $0.6\%$. Multiplied by the number of categories we considered (8), the probability is still less than $5\%$.

CLASS Scores and Student Backgrounds

Physics breadth courses are designed for non-science students with little prior physics experience. However, 44% of the students had taken grade 12 physics in high school, and 37% identified their area of study to be either physical sciences, life sciences or computer science. We compared CLASS scores and shifts for the arts and science majors, and the students with and without grade 12 physics.

We found no statistically significant differences in scores or shifts between the arts and science students in our courses. However, prior physics coursework correlated reliably with CLASS scores. The results are presented in Table 2. At the beginning of the course, the 203 students who had not taken grade 12 physics had an average overall CLASS score of $54.8 \pm 1.0\%$, while the 152 students who had taken grade 12 physics got $61.2 \pm 1.2\%$ - a difference of over $5\sigma$. It could be expected that students who took physics in high school also took other science courses, and were therefore exposed to scientific reasoning before even coming to U of T. A similar positive correlation between high school physics and pre-course CLASS scores was found at our neighbour, Ryerson University[4].

As seen in Table 2, the shifts in CLASS scores over one semester for students who had taken grade 12 physics were insignificant. However, the overall shift for students without grade 12 physics was $+2.2 \pm 1.1\%$, and there were three categories, PI, PSC and PSS, for which we measured a statistically significant upward shift. The paired $t$ test probabilities for these three categories having no shift were $0.8\%$, $0.9\%$ and $0.5\%$, respectively. This suggests that students with less of a science background have more to gain from breadth courses.
The Effects of Physics Breadth Courses on Student Attitudes... (Harlow et al.)

**TABLE 2**

**Pre-course CLASS average scores for students with different high school backgrounds taking either of the breadth courses in this study. Average percentage of favourable responses is shown, with standard error of the mean in parentheses. The shift from the beginning of the course to the end of the course is also shown. Shifts that are statistically significant at the $p < 0.05$ level are shown in bold.**

<table>
<thead>
<tr>
<th>CLASS category</th>
<th>No Grade 12 Physics ($N = 203$)</th>
<th>Grade 12 Physics ($N = 152$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-course</td>
<td>Post Minus Pre</td>
</tr>
<tr>
<td>Overall</td>
<td>54.8 (1.0)</td>
<td>+ 2.2 (1.1)</td>
</tr>
<tr>
<td>Personal Interest</td>
<td>56.3 (1.8)</td>
<td>+ 6.1 (2.2)</td>
</tr>
<tr>
<td>Real World Connections</td>
<td>67.7 (2.0)</td>
<td>+ 4.5 (2.4)</td>
</tr>
<tr>
<td>Problem Solving General</td>
<td>57.6 (1.7)</td>
<td>+ 4.4 (1.9)</td>
</tr>
<tr>
<td>Problem Solving Confidence</td>
<td>54.7 (2.1)</td>
<td>+ 6.7 (2.5)</td>
</tr>
<tr>
<td>Problem Solving Sophistication</td>
<td>38.3 (1.8)</td>
<td>+ 6.5 (2.3)</td>
</tr>
<tr>
<td>Sense Making and/or Effort</td>
<td>68.0 (1.5)</td>
<td>- 1.7 (1.8)</td>
</tr>
<tr>
<td>Conceptual Connections</td>
<td>50.1 (1.8)</td>
<td>+ 2.7 (2.1)</td>
</tr>
<tr>
<td>Applied Conceptual Understanding</td>
<td>37.2 (1.5)</td>
<td>+ 2.8 (1.9)</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

This was an exploratory study of CLASS results for physics courses aimed at non-science students. We did not find negative shifts over a single-semester, as reported in other studies [1–3]. We found a slight positive shift for our course that involved interactive teaching techniques and hands-on tutorial activities. We also found a positive shift for students who had not taken grade 12 physics in high school. Students who had taken grade 12 physics started out with better attitudes, but their attitudes did not shift over the semester.

Future work could focus on which classroom activities have a positive effect on student attitudes, and what assessment methods would better measure attitudes about science.

**REFERENCES**

"Peer Instruction or Peer Pressure?" Using Conceptual Questions to Probe the Dynamics of Active Classrooms

by Martin L. Williams and Stephen Glazier

Many instructors of undergraduate courses have reported significant learning gains after Peer Instruction [1–3]. A popular peer instruction approach is the use of in-class concept questions with personal response systems or “clickers.” Peer instruction encourages students to verbalize their thinking and interact with peers to arrive at an answer [2]. Typically, students’ first answer questions posed by the instructor individually, they then discuss the same question with peers and re-vote before the answer is revealed. There are two alternative hypotheses commonly used to explain the increase in conceptual understanding observed [4, 5]. The constructivists view is that active engagement of students during discussions with peers lead to increased conceptual understanding. Transmissionists argue that students learn by being told the correct answer so the student that seems the most knowledgeable “teaches” his knowledge to the rest of the group. While some work has been documented focusing on interaction mechanisms; Smith et al. [4, 5] used paired sets of similar clicker questions to evaluate the interaction mechanism, there is nothing in the literature that focuses on the dynamics of the interaction. More specifically how does peer influence, random guessing and students who voted but did not engage in peer interaction influence measured gains. To explore the merits of these alternatives we applied a modified clicker protocol using a survey instrument as a third clicker vote. We evaluated the effects on normalized learning gains in three undergraduate courses using the Hake formula:

\[ <g> = (\text{post} - \text{pre}) / (1 - \text{pre}) \]

METHODS

This study was conducted in two undergraduate physics courses required for majors (IPS*1500 - Fall 2012 and IPS*1510 - Winter 2013) and an introductory physics for the biological sciences non-majors course (PHYS*1020 - Fall 2012). These courses were taught in the Department of Physics at the University of Guelph, by one of the authors: M.W. The classes met for three 50-min sessions per week. Typically, averages of two to three in-class clicker questions were asked per session throughout the semester and students were encouraged to discuss questions with their neighbours. No participation marks were awarded for answering questions but students had an incentive to do well because they were told that clicker type conceptual questions would constitute a third of their final exams. After listening to a lecture students answered clicker questions individually to provide a measure of their understanding. They then discussed with their neighbours and voted on the same question again. Histograms of student responses were only shown after the second vote. In the modified approach used in this study an additional step was added to this routine to separate out genuine peer instruction as opposed to responses due to guessing and peer pressure; after the second vote students were immediately asked to indicate, via a third vote, which of the statements listed below best indicate the reason for their voting choice.

Which statement best describes your participation?

(a) I changed my answer after discussing with peers
(b) I changed my answer and did not discuss with peers
(c) I did not change my answer after discussing with peers
(d) I did not change my answer or discuss with peers
(e) I randomly guessed or overheard someone say the answer

Summary

In-class concept questions were employed in various introductory physics courses. After voting, students participated in peer discussion then re-voted. To distinguish between various interaction alternatives, a third question was then immediately administered investigating students’ attitudinal changes during voting. Normalized gains differed substantially if students who voted but reported no peer interaction and random guessing were excluded from the data. Gains reported in the literature should be interpreted with caution.
Using Conceptual Questions to Probe the Dynamics... (Williams/Glazier)

![Graph showing constituent response types and attitudes for non-majors (PHYS1020). The unfiltered gain was 28%, if the effects of guessing and students who did not engage in peer discussion are removed from the data the true gain is 33%. Key: R = Right W = Wrong NV = No Vote R-R = Student with a right answer before and after genuine P.I.](image)

Only responses (a) and (c) were considered as genuine peer instruction (P.I.) in this study. Prior to this, and as is commonly reported elsewhere, it was automatically assumed that gains recorded after the second vote was due only to peer interaction.

Questions where the first vote was greater than 75% correct were immediately discarded from the study with no second and third votes done. It was believed that these questions would provide very little opportunity for gains through peer interaction. Data from 489 students was collected and analysed from three courses for this study.

RESULTS AND DISCUSSION

The results from both majors and non-majors indicate the effect of guessing on the measured learning gains is not statistically significant and could be considered as negligible. Using data pooled from individual responses to the attitudinal statements of the third vote, the average percentage of students guessing for non-majors (Fig. 1) was 3%. The average for all three courses combined (Fig. 2) was 2%. Our results show (Fig. 1) that for non-majors, the calculated normalized learning gain of 0.28 only represent 84% of students genuinely participating in peer discussion. If the effects of guessing and those students who did not engage in any peer interaction are accounted for in the data set, then the true gain increases to 0.33. True gain was found by omitting responses from students who did not participate in the before discussion questions from the “pre” average and after discussion questions from the “post” average calculations (1–4% of students) as well as those students who declared they had guessed. This result represents an inflation of 5% from our initially calculated gain. When these calculations were repeated for both majors and non-majors together, where the averages are for the aggregate data, the values obtained are comparable (Fig. 2). True gain was found to be higher than the unfiltered gain in all three courses examined. The majors had increases of 20–50% (IPS*1500) and 53–59% (IPS*1510). These large increases and the reported 15% self-change in IPS*1500 (Fig. 2) may be partly due to smaller class sizes for the majors. Students who appeared not to be participating constructively (less than 50% participation rate or random button pushing) were not included in the analysis. The number of students that changed responses or stayed with their answer agreed with the self-reported changed and stayed results within 6%, and the number of non-voting students agreed to within 1% (Fig. 1).
CONCLUSIONS AND FUTURE DIRECTIONS
Our preliminary results suggest that the effect of random guessing does not significantly affect the measured normalized learning gains. However, we found that the combined effect of random guessing and students who voted but did not participate in the peer interaction process was substantial. Our data shows a spread of 5–9% gain inflation if these effects are considered.

These results suggest that some caution should be applied to interpreting student gains reported in the literature.

REFERENCES
The Uncertainty of Grades in Physics Courses is Surprisingly Large

by David M. Harrison

Almost all teachers are required to submit final grades for their students. In this note we discuss the uncertainty in those grades with an emphasis on grades in physics courses. We will estimate that the statistical uncertainty in final grades is at least 4% out of 100%, and is probably significantly higher than this. The implications of this result on things like calculating Grade Point Averages are large.

For multiple-choice tests there is a large body of statistical work\(^1\), which we will briefly review. The reliability \(r\) of a particular test can given by the Cronbach \(\alpha\) coefficient\(^2\):

\[
r = \alpha = \frac{K}{K-1} \left[1 - \frac{\sum_{i=1}^{K} p_i (1-p_i)}{\sigma^2}\right]
\]

where \(K\) is the number of questions on the test, \(p_i\) is the fraction of correct answers for question \(i\), and \(\sigma\) is the standard deviation of the scores on the test. The values of \(r\) are between 0 and 1. Professionally developed high-stakes standardised tests achieve reliabilities of at least 0.9, and by convention values of \(r\) less than 0.5 indicate a poorly designed test. It turns out that the reliability of a test increases as the number of questions on it increases\(^3-5\).

From the reliability, the standard error or measurement \(s\) can be calculated\(^6\). This is the statistical uncertainty in each individual student’s grade on the test, and is given by:

\[
s = \sigma \sqrt{1-r}
\]

The interpretation of \(s\) is similar to the standard deviation of experimental measurements: 1 \(s\) corresponds to a 68% confidence interval, 2 \(s\) to a 95% confidence interval, etc.

**Summary**

The statistical uncertainty in final grades in Physics courses is shown to be at least about 4% out of 100%, and is probably significantly higher than this.

For physics tests the issue of using multiple-choice questions as opposed to long-answer questions, which are marked in detail with part grades awarded, is religious, and we will try to avoid those arguments here. In our large (900-student) 1st year university physics course primarily for life-science students, we typically have about 75% of the grades on each test and exam determined by multiple-choice questions, and about 25% determined by one or more long-answer questions. Since our typical multiple-choice question takes the student about 5 minutes to do, we can have between eight and sixteen such questions on each test and exam. This is different from tests in subjects that are fact-based, such as introductory psychology, where colleagues in those Departments report that each question on tests and exams in their introductory course takes the students about 1 minute to do, so in the same time period up to 50 questions can be asked.

Over the past couple of years the best reliability we ever achieved on the multiple-choice section of our tests and final exam was \(r = 0.70\) with a corresponding standard error of measurement \(s_{MC} = 11\%\). Thus we can only distinguish between grades on this part of the test to within an uncertainty of over a full letter grade. The comparatively poor reliability and corresponding high error of measurement is undoubtedly in part because of our lack of skill in setting a good test, but it also a reflection of the small number of questions we can ask. Courses in, say, introductory psychology, with more multiple-choice questions, often achieve higher reliabilities and smaller errors of measurement than we have managed to achieve. Below we will assume this best value of \(s_{MC} = 11\%\) for all tests and exams in a model course.

Therefore, our calculation of the uncertainty in the final grade is definitely a lower bound.

For the long-answer section of our tests and exam, we do not know of any way to estimate a standard error of measurement \(s_{LA}\). For our typical test with 75% multiple-choice and 25% long-answer grades, the test grade is:

\[
\text{test grade} = (\text{multiple-choice } \pm s_{MC}) \times 0.75 + (\text{long-answer } \pm s_{LA}) \times 0.25
\]
The uncertainty of grades in physics courses is surprisingly large (Harrison)

Since the values of \( s \) are uncertainties of precision, they should be combined in quadrature, i.e. the square root of the sum of the squares. Thus the uncertainty in the test grade \( s_T \) is:

\[
 s_T = \sqrt{(s_{MC} \times 0.75)^2 + (s_{LA} \times 0.25)^2}
\]  (4)

If we assume that the multiple-choice and long-answer sections have equal standard errors of measurement, \( s_{MC} = s_{LA} = 11\% \), i.e. that they both are equally effective in assessing students, then from Eqn. 4 \( s_T = 8.70 \approx 9\% \). We will also assume that the standard error of measurement on the final exam, \( s_{final} \), also is 9\%.

The uncertainty in the test grade given by Eqn. 4 is not highly dependent on the uncertainty in the long-answer section. Fig. 1 shows the value of \( s_T \) for values of \( s_{LA} \) from 1\% to 20\%. The value of \( s_T \) varies from 8.25 to 9.65\%. In the figure, the horizontal line is the value of Eqn. 4 for the assumed values of \( s_{MC} = s_{LA} = 11\% \).

We will also assume that for the parts of the final grade in the course that are not from tests and the exam, such as problem sets or laboratories, there is no error of measurement in these grades, i.e. that they are perfect in assessing students; this assumption is certainly not true.

Often in our course, we have two term tests and a final exam. Each test counts for 15\% of the grade in the course and the final exam counts for 40\%. Therefore, using our extremely optimistic assumptions the final grade in the course is:

\[
 \text{final grade} = (\text{Test1} \pm 9) \times 0.15 + (\text{Test2} \pm 9) \times 0.15 + (\text{Final} \pm 9) \times 0.4 + (\text{term work} \pm 0) \times 0.30
\]  (5)

The standard error of measurement for the final grade, \( s_{FG} \), is:

\[
 s_{FG} = \sqrt{(s_{Test1} \times 0.15)^2 + (s_{Test2} \times 0.15)^2 + (s_{Final} \times 0.4)^2 + (0 \times 0.3)^2}
\]  (6)

Since we have made many assumptions that make these errors lower bounds, the actual uncertainty in the final grade is certainly larger than the value obtained by just propagating the errors in Eqn. 6. Therefore the result of the calculation gives us:

\[
 \Delta(\text{final grade}) > 4\%
\]  (7)

Thus final grades of, say, 76\% and 77\% are the essentially identical within errors.

The dominant contribution to the result Eqn. 7 is from the uncertainty in the final exam. If we model a course with one term test counting for 30\% of the grade in the course, with the final exam still counting for 40\%, the uncertainty in the grade rises to \( \Delta(\text{final mark}) > 4.5\% \).

We made many assumptions to get to Eqn. 7. So the calculation is a type of Fermi Question: different sets of reasonable assumptions will lead to a very similar result. Therefore we believe that the uncertainties in final grades in our courses are probably comparable to those given to students in most physics courses at most schools.

At the University of Toronto, a 76 corresponds to a letter grade of B and a 77 corresponds to a letter grade of B-plus. For calculating a Grade Point Average (GPA) the university makes a distinction between B and B-plus with the former having a value of 3.0 and the latter 3.3. So the effect on the student’s GPA of these two essentially identical final grades is large. This same ill-advised procedure is common in one form or another at many schools.

In Toronto we have had considerable discussion about what to do about this, but without a satisfactory resolution. For example, we could convert grades of 76 to 77. But then what about 75? And if we change 75 to 77, then what about 74? We have also considered rounding all grades to the nearest 5, but that would mean that a grade of 78 goes to 80, an A, while 77 goes to 75, a B. We also discussed rounding up to the nearest grade that is evenly divisible by 5, but this makes a huge distinction between a 75, which stays the same, and a 76, which goes to an 80. Perhaps the only resolution is to drop the GPA calculation entirely.

Failing that institutional change, when we are confronted with the list of student names and final course grades that we are to turn in at the end of the course, we need to at least be sensitive to the large uncertainty in the numbers.
REFERENCES


2. L. Cronbach, “Coefficient alpha and the internal structure of tests,” Psychometrika 33, 297 (1951). There are other statistics that measure the reliability, such as the Kuder-Richardson Formula 20, but for our purposes they are all equivalent.


Epistemic beliefs refer to individuals’ implicit thinking about the nature of knowledge and knowing, which have direct and indirect effects on student learning, such as the types of learning strategies that students use, their readiness for conceptual change and their self-regulated learning[1].

Normally, with education and experience, an individual develops from an absolutist to an evaluatist: the former sees knowledge as black and white, and as static fragmented facts that are handed down by experts or authorities, whereas the latter sees knowledge as interconnected, constructed and should be weighed or evaluated with evidence. For example, in science teaching and learning, novice learners tend to view science as loosely connected bits and pieces of knowledge which should be separately learned, in contrast to the web of meaningful interconnections perceived by science experts[2]. The novice way of thinking is less educationally productive, since it tends to undermine learners’ interest and motivation[3] and prevent them from persevering with science and engineering careers[4].

How to bridge this novice-expert gap? Since an individual’s personal epistemology develops slowly and epistemic change does not come easily, teachers need to create learning environments to enhance epistemological development in novice learners. If they can successfully identify where the gap or epistemic conflict is, the instruction can be designed to address the specific conflict, as McCaskey stated:

If a student believes that knowledge in physics should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict. Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict. Finally, if a student is being presented material in a fragmented way, but he or she would expect or believe the material should fit together more cohesively, that would cause another type of conflict. These conflicts (or, conversely, a lack of these conflicts) can affect learning above and beyond specific difficulties with mathematics or concepts[5].

THREE LEARNING ACTIVITIES

Kalman and colleagues[6] have designed and implemented instructional interventions aimed to promote epistemic change in novice learners in introductory physics courses. All activities have been previously evaluated as stand-alone interventions[7].

Reflective writing was designed to promote students’ ability to identify and relate concepts, to look beyond a specific chapter, and to identify conceptual difficulties or conflicts they are having with the material. Students who are truly involved in this activity are more likely to see the interconnected nature of knowledge, and in establishing the connection they are more likely to learn to evaluate their own knowledge against knowledge from the learning material. The following is from a student’s reflective writing sample[8].

The theoretical content of this chapter is not all that different from chapter seven and fairly straightforward. It is more of a merging of the concepts of energy with more familiar problem solving strategies . . . To me, a deceleration caused by kinetic friction of, say, 10 m/s² would produce an enormous amount of heat. I have never thought about where that energy goes till now. My first reaction was that the tire would not be able to handle that amount of energy transfer, which I now know must be false . . . What I still do not understand is if the capacity of brake pads to absorb heat is higher than I expected, or rather if the rate at which deceleration translates to heat is much lower.
The in-class collaborative group exercises were designed to provide students a learning environment to question their alternative personal scientific conceptions and to have them exposed to other perspectives. For example, in one of the exercises, students were asked to compare the motion of a free-falling body with a horizontal projectile. Then two groups of students would be asked to present their ideas and to have other students question and challenge their proposed ideas. Once students’ perspectives are exposed to “public” scrutiny, their certainty about knowledge is questioned or reevaluated.

The critique writing activity is basically an argumentative essay, in which students have to put forward as many possible arguments in favor of all the conceptual viewpoints raised in class and then point out which viewpoint is correct from an experimental point of view. Argumentation may promote deeper processing of the learning content, and students’ dispositions to engage in argument are closely related to the epistemic beliefs they hold[9], and will reciprocally influence their beliefs about knowledge.

The intervention effect on students’ epistemic beliefs in reflective writing group was compared to that in summary writing group. Overall, results in the dimension of simplicity/certainty showed that novice science learners become more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving, which can be better learned by relating to their prior knowledge and their life experience. Change was also found with their beliefs in the attainability of truth: students believe more and more that truth is attainable. However, no significant change was found in their beliefs about the source of knowledge and the justification for knowing. More extensive and prolonged intervention is needed to effect more profound change, and to help students internalize the change.

RESULTS
The intervention effect on students’ epistemic beliefs in reflective writing group was compared to that in summary writing group. Overall, results in the dimension of simplicity/certainty showed that novice science learners become more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving, which can be better learned by relating to their prior knowledge and their life experience. Change was also found with their beliefs in the attainability of truth: students believe more and more that truth is attainable. However, no significant change was found in their beliefs about the source of knowledge and the justification for knowing. More extensive and prolonged intervention is needed to effect more profound change, and to help students internalize the change.

REFERENCES
INVENTION ACTIVITIES: A PATH TO EXPERTISE

BY JAMES DAY, WENDY ADAMS, CARL E. WIEMAN, DANIEL L. SCHWARTZ, AND DOUGLAS A. BONN

Different instructional techniques are useful for different learning outcomes. Social modelling, for example, leads to imitation\(^1\), whereas positive reinforcement leads to repetition\(^2\). For many domains, a major goal of instruction is the development of flexible understanding\(^3\). This includes abilities to handle and learn from novel situations outside of the instructional examples themselves\(^4\). The desired outcome is transfer. Transfer has been difficult to achieve with current methods of instruction\(^5\). Therefore, we have been developing a new method of instruction that better supports the outcome of transfer, especially transfer that helps students learn in the future.

To best prepare our students for future learning (of concepts related to the proper statistical treatments of real data), we use invention activities\(^6\). An invention activity is one that helps students to notice important structural features and prepares them to learn from expert interpretations. This paper highlights the relevant differences between novices and experts, and details how instructors can build their own invention activities to better prepare their students for future learning.

THE DIFFERENCE BETWEEN EXPERTS AND NOVICES

Learning is how novices become more expert. The study of differences between experts and novices has revealed distinctions in how they organize and apply their existing knowledge, and how they learn new ideas\(^3,7\). The difference between expert and novice is more than a general capacity, such as memory or intelligence, and is more than a larger bank of strategies and procedures.

Experts have developed a capacity to detect relevant structure in evidence, whereas novices often overlook cues that elicit new lines of thought. Experts possess an integrated framework for coordinating their knowledge, allowing for the effortless and flexible retrieval and combination of organized facts from memory, whereas novices tend to rely upon fragmentary memorization. Experts’ knowledge encodes its applicability conditions and they recognize when something conflicts with prior knowledge, whereas novices’ knowledge often does not reflect the variety of situations for which it may be useful and they often fail to recognize contradiction. Experts approach new situations with an eye towards underlying principles and can appreciate whether disparate instances have the same underlying structure, whereas novices focus on surface features\(^8\) and tend not to first organize the information\(^9\).

Understanding expertise is important because it provides meaningful insight into the nature of thinking and problem solving.

INVENTION ACTIVITIES

What they are

Invention activities can provide a path for the mental journey to expertise. An invention activity in an instructional lab helps students focus on the relevant underlying structure in data and to build a mental framework that prepares them to comprehend standard representations. Like any other innovation in the classroom, care must be taken: without proper design and implementation, students can become frustrated and lose their motivation.

A good invention activity has a few specific characteristics\(^10\). To put some of these characteristics into context, parts of a “real” invention activity (found, in full, in Day et al.\(^11\) and designed to prepare students to learn about histograms and standard deviations), are provided for the reader. First students receive four data sets, summarized for the reader in Table 1, associated with four different water flow meters. They need to invent a procedure for graphically representing the data for each device. Second, they need to invent a “blue-ribbon factor”: a value for how well each device measures the flow rate of water. They are told that a smaller “blue-ribbon factor” means the device performs more reliably.

Summary

We have been developing a new method of instruction that better supports the outcome of transfer, especially transfer that helps students learn in the future.

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Wendy Adams, University of Northern Colorado

Carl E. Wieman, Stanford University

Daniel L. Schwartz, Stanford University

and

Douglas A. Bonn, University of British Columbia
TABLE 1

The data, in summary form, associated with the invention activity.

<table>
<thead>
<tr>
<th>machine</th>
<th>N</th>
<th>μ</th>
<th>σμ</th>
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<tr>
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<tr>
<td>D</td>
<td>10</td>
<td>9.9 mL/s</td>
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</table>

How to make one

A good invention activity should present a readily interpretable goal and engaging scenario to the student. The student should be applying all their cognitive resources to solving the task, rather than figuring what is being asked\(^{[12]}\). The goal of the activity is, in most instances, to invent a concise and consistent description of the important features across some given cases. Typically, the description entails integrating multiple features into a single representation (mathematical, graphical, or otherwise). A concise description of multivariate data is consistent with what experts do when trying to describe or present real data.

The cases students receive must contrast\(^{[4]}\). Contrasting cases can help novices to notice the features of the examples that are important. A random set of different examples are just confusing. An invention activity should present multiple cases at once, so that students notice both the structure itself and the structural variations across cases that go beyond their surface differences. Ideally, contrasting cases vary systematically on key parameters, so that students can discover how the variations relate at a deeper, structural level. See the grayed cells in Table 1 for the contrasts.

The context of the contrasting cases is delicate. If the cases are too close to the course material, students may resist the invention activity because they cannot find the answer in the book. If the cases are too far afield from their common sense, students might not be able to recognize when a description or representation fails for a given case.

Invention activities should be devoid of domain-specific jargon for practical reasons. Specialized language triggers the common student response of equation hunting, rather than the desired engagement of trying to learn. When students arbitrarily force a previously learned procedure or concept, a likely culprit is language that triggers a “look up” response. It is important to make sure that students engage in the inductive task of learning rather than just trying to get the right answer. Recalling familiar concepts should not be discouraged, but it should be done for the goal of learning.

The level of difficulty associated with the invention activity should be set so that students can achieve partial success, but it is not necessary for students to discover the expert solution that covers all cases\(^{[13]}\). Recognizing a portion of the underlying structure is sufficient to prepare students to learn the expert explanation.

Invention activities are ideally completed collaboratively—pairs maximize opportunities for contribution while minimizing concerns of group composition. Moreover, conveying their ideas to one another deepens their understanding because the student has to explain it in a consistent manner that their peers can understand. Similarly, analyzing the ideas of others yields a more thoughtful consideration. In this way, small group work fosters deep learning. Furthermore, memory encoding, storage retention, and retrieval are heightened when one establishes meaning and understanding through presentation to others.

Because of their complexity, invention activities must go through a design cycle. One should user-test the activity with a few representative students first. Then, try it at the class level, where student motivations and variability will be different from one-on-one testing.

When designing invention activities, rely on your expertise to isolate the fundamental structures that students need to recognize. Consider each case as an experimental treatment to isolate each key variable. If the goal is to prepare students to learn an equation, then the contrasts need to highlight the variables that will appear in the equation. If you know that students have a consistent misconception, include a contrasting case that causes the misconception to fail. Your activity does not have to be highly entertaining, but it should be approachable. If the invention activities work as planned, your next task is to provide an explanation of how the cases map into the canonical explanations of your field.

ACKNOWLEDGEMENTS

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REFERENCES

Participating in the Physics Lab: Does Gender Matter?

By Natasha G. Holmes, Ido Roll, and Douglas A. Bonn

It is a well-studied notion that women are under-represented in the physical sciences, with a “leaky pipeline” metaphor describing how the number of women decreases at higher levels in academia. It is unclear, however, where the major leaks exist and what factors are responsible for this. Our focus here is on women in physics with an emphasis on practical laboratory work.

A theoretical framework is under development whereby the process of learning physics (and also learning “physicist”) is described as a gendered experience. As students begin to develop an identity of what a physicist is, they are also developing masculine and feminine identities of physicists. The authors described how female students perceived the existence of separate male- and female-type roles in physics lab work that connect to traditional notions of femininity and masculinity. Another study found experimental evidence of this in middle school classrooms, with male students handling lab equipment significantly more often than female students during hands-on activities. The group sizes in this study, however, varied between 2 and 5 students. It is possible, then, that these results are based primarily on issues of unbalanced genders in the group sizes. That is, it has previously been shown that problem solving discussions between groups with more male students than female students tended to be dominated by the male students. It is, thus, not surprising that male students would also dominate with hands-on equipment if there is a gender imbalance in the group.

We aimed to study this issue further and in undergraduate classrooms through observations of how male and female students in a first-year physics lab divide roles while taking data. To address any issues of gender imbalance in the groups, we used only mixed-gender pairs of students (one male and one female student). We were testing against the null hypothesis that female students spend just as much time handling the equipment during an experiment as the male students. If the use of equipment is dominated by other psychological or sociological phenomena, then no gender effect should be observed.

Method

Participants were students enrolled in a first-year honours physics course. In the lab portion of this course, students conduct an experiment each week in pairs or groups of three. The groups are randomly determined by the instructor or TAs and change each week. During the week of the study, the pairs of students were organized in a semi-random manner such that the number of mixed gender pairs (one female, one male) was maximized. Only the mixed gender pairs were included in the study. The observations took place across a single week near the end of the first term of the course when students were conducting a mass-on-a-spring experiment. The experiment asked students to determine the spring constant of a spring using Hooke’s law (measuring the extension as a function of mass) and harmonic oscillation properties (measuring the period of oscillations as a function of mass).

Mixed-gender pairs were observed throughout the hands-on portion of the lab and their actions were recorded at regular time intervals as to which member of the pair was handling the equipment. One researcher discreetly monitored the class during the lab sessions and would sweep across the lab room every five minutes to record a behaviour code corresponding to each student’s activity on a map of the classroom. It would take at most two minutes to sweep the whole classroom. The observer would continue to sweep until all of the students had completed their measurements and were conducting analysis or writing in their lab books. The only code included in the final analysis was which student was handling the equipment in each pair, which was then converted to a binary coding of whether the female student was using the equipment during that time interval. If neither member was actively using the equipment...
Participating in the Physics Lab: Does Gender Matter? (Holmes et al.)

during an observation interval the observation was removed from the analysis (that is, the group was averaged over fewer time intervals). If both members were using the equipment during a time interval, that observation would count as half of an observation. Each pair was given a score reflecting the fraction of observations, out of those where the equipment was in use, that the female partner was the one using the equipment. That is,
\[
F_{\text{Score}} = \frac{\# \text{ observations female was using equipment}}{\# \text{ observations equipment was being used}}. \quad (1)
\]

Thus, a score of 1 means that the female was in charge of the equipment the whole time, a score of 0 means the male was in charge of the equipment the whole time, and 0.5 means they shared the usage equally.

RESULTS

On average, the female students handled the equipment 40% ± 6% of the time, which was not statistically different from 50% through a one-sample t-test: \( t(36) = -1.66, p = 0.106 \). Fig. 1 shows the distribution of the fraction of time the female partner was using the equipment. A flat distribution would represent an equal likelihood that any individual spends any percent of time on the equipment (that is, it is just as likely that either partner would take over the equipment or that all use would be shared). A chi-square test of independence showed that the distribution in Fig. 1 may be different from a flat distribution: \( \chi^2(9) = 16.24, p = 0.062 \). While not significant at the 0.05 level, this result, together with the distribution, suggests that it could be more likely that one student uses the equipment the majority of the time. A moderate, positive skewness of 0.4 additionally hints that it may be the male partner who more often takes over using the equipment (demonstrated by the peak in the bin representing groups where the female only used the equipment 0–20% of the time). These results are by no means conclusive, but do motivate further investigation with a larger sample size.

DISCUSSION

In this study, we looked at how often female students in mixed gender pairs use the equipment in a physics lab experiment compared to male students. We found evidence that male students may be more likely to take over the equipment (a large peak in the groups where the male student used the equipment more than 80% of the time). While the effect is still marginal at this point, due to a sample size of only 37 pairs, this motivates further investigation with a larger group of students. We aim to repeat the measurement this coming year to increase our sample size and explore this result further.

It is likely that the use of equipment in a lab experiment is dictated by several factors such as physics knowledge, personalities, previous experience conducting experiments, and confidence levels of the group members. What this research suggests is that whichever other psychological or sociological phenomena dictate the use of lab equipment, these traits may differ by gender. Future research should examine whether any patterns of behaviours exist with same-gender pairs and include additional demographic or behavioural characteristics of students in mixed-gender pairs to identify what may be causing these differences. Future studies could also determine what classroom interventions could be used to promote female students’ engagement with equipment during hands-on experiments. Any interventions, however, risk increasing students’ awareness of the difference in their roles, which could further expose them to the gender stereotypes in physics, thus inducing stereotype threat and reinforcing the imbalance in participation.

REFERENCES


PROMOTING STUDENTS’ SCIENTIFIC THOUGHT USING REFLECTIVE WRITING IN INTRODUCTORY PHYSICS COURSES

by Wahidun Nahar Khanam and Mandana (Mandy) Sobhanzadeh

Knapper[1] identifies several problematic areas in university teaching such as: [A] Teaching remains overwhelmingly didactic and reliant on traditional lectures, and assessment methods are often trivial and inauthentic; [B] “Evaluation of teaching effectively and learning outcomes is often superficial” (p. 238). Ideally, we need to create learning environments in which students do not only succeed in undergraduate science courses, but also develop the necessary expert-like thinking in physics, meaningful approaches to learning, as well as gain transferrable skills vital for productive participation in a modern society. Remedies for these issues include using the reflective writing activity in introductory Physics courses and the collaborative group laboratory activity called “Labatorial”[2] in the laboratory.

REFLECTIVE WRITING

When university students are enrolled in science courses, they can have great difficulty reading scientific texts. Part of the reason is that for a student taking a science gateway course the language, ontology and epistemology of science are similar to a foreign culture[3]. Reflective writing is evidence of reflective thinking. In an academic context this usually involves looking back at something and trying to analyze the event or idea (thinking in depth and from different perspectives, and trying to explain) and also thinking carefully about what the event or idea means for you and your ongoing progress. Since Egger[4] introduced hermeneutical philosophy into science education research, several studies have been conducted that have applied a hermeneutical perspective in science education[5–8]. Kalman[3] has developed what he calls ‘reflective writing’, which helps students begin to analyze the materials in the textbook according to the modern theory of hermeneutics as developed by Gadamer[9]. Kalman explained, the hermeneutic approach starts by having students initiate a self-dialogue about each textual extract. Within the framework of such a dialogue, there exists two “horizons”[9]. There is the horizon that contains everything that a student believes from the particular vantage point of encountering the textual extract. The second horizon encompasses the potential in the textual extract; the sense in which the words, in the textual extract, are related within the language game understood by the author of the textbook[5]. Gadamer[9] used the term horizon as “the range of vision that includes everything that can be seen from a particular vantage point” (p. 269). The hermeneutical circle[5] involves the interaction between our construct of the unfamiliar with our own viewpoint that deepens with each pass.

Students come into science classes with their own perceptions and beliefs, which make sense in explaining observations in their life world and are reasonable to some extent. Therefore, when a student comes to a text, two horizons are in view: the horizon of the student (Horizon A) and the horizon of the textbook (Horizon B). When students read the text they build their new horizon (A). This horizon is the combination of students’ parts i.e. the students pre-understanding, experience from their life world and experience from the textbook. This is the students’ whole. The textbook whole (Horizon B) is a combination of its parts.

The hermeneutical circle begins when two horizons overlap. In Fig. 1A, the part “C” means that the student’s understanding and the meaning found in the textbook overlapped in this area. But the rest of horizon A contains

SUMMARY

Many students’ have enormous difficulty understanding the basic concepts in textual materials[3]. Therefore, instructors cannot rely solely on traditional lectures to reach students’. It is necessary to supplement lectures with other activities such as reflective writing[4] and collaborative group activities[4]. This article focuses on using the reflective writing and laboratory exercises to help students’ understand the conceptions covered in introductory physics courses.
Promoting Students’ Scientific Thought... (Khanam/Sobhanzadeh)

A mismatch of the students’ understanding of the textbook and the meaning found in the textbook. So they may try to correct their understanding in reviewing the textbook again to create a new horizon (A), and then harmonize again the two horizons. Look at the part “D” in Fig. 1B. If this area is increased, it means that their horizon shifted to the horizon projected by the textbook. In every pass of the circle the students’ horizon comes closer and closer to the horizon projected by the textbook. The hermeneutical circle ends when two horizons overlap completely. Therefore, understanding is a process of fusion of the two horizons.

LABATORIAL

In physics introductory courses at Mount Royal University, traditional lab sections were replaced by Labatorials, which have been developed by the Physics Education Group at the University of Calgary. The name “Labatorial” comes from a combination of “laboratory” and “tutorial”. In such a lab students use a worksheet which contains instructions for the experiment, conceptual questions, calculation problems, and computer simulations. By using this new style of lab we try to highlight the physics concepts of each lecture and allow students to present and share their ideas with one another. In Labatorials, students start working on a Labatorial worksheet in groups of 3 or 4 students. Labatorial worksheets include both instructions for the exercise and space for the responses to specific questions. Discussions within the group are not only allowed, but mandatory. After doing several exercises students arrive at a “checkpoint” which tells them to pause in their work and call over their lab instructor. The lab instructor will then check the group’s work and engage the entire group in conversation. If the work preceding the checkpoint is satisfactory, the instructor will check off that portion of the worksheet, and students will be allowed to move on to the next section, continuing in this manner until they have finished the entire Labatorial. If they don’t demonstrate sufficient competence on the material, they are asked to revise their work with further group discussion. When they think they have resolved the problems, they call the lab instructor again to check their work. If they complete all of the checkpoints on their worksheet, they get full credit for the worksheet.

OBJECTIVES AND PRELIMINARY FINDINGS:

In 2013/14, we are using the reflective writing activity as part of the Labatorial method for first year science students participating in the introductory physics courses (Phys1201 and Phys1202) at Mount Royal University. We are also using reflective writing as a part of an introductory calculus-based mechanics course (PHYS 204) at Concordia University. The main objectives or research questions are, what do students do during reflective writing? Do they write using the procedure of reflective writing activity in the manner of a hermeneutical circle? Do these activities change their scientific thought? Do they identify their problems about learning physics and Labatorials? etc. Our preliminary data (writing products) showed that students are able to construct a scientific mindset using the procedure of reflective writing activity in the manner a hermeneutical circle.

IMPLEMENTATION

These activities should help students to learn physics holistically. They also help them to understand how physics relates to real life.

ACKNOWLEDGEMENT

The authors gratefully thank Dr. Calvin S. Kalman for his valuable comments and help.

REFERENCES


Reforming High School Physics: Implementing a Studio Physics Program in Toronto

by Christopher Meyer

At York Mills Collegiate Institute, I see classes of 30 students for 70 minutes every day in a typical semester of physics. What is the best educational use of our time together? This question helped guide my development of a research-based studio physics program for grades 11 and 12. I adapted techniques and materials from numerous highly-regarded physics programs including Workshop Physics\(^1\), Physics by Inquiry\(^2\), the University of Toronto Physics Practicals\(^3\), Physics Union Mathematics\(^4\) and many others. The reformed grade 12 course has run for four years (eight semesters) and the grade 11 course for two years (four semesters). Two other physics teachers are trained in the program and run it with me.

PROGRAM PHILOSOPHY AND STRUCTURE

Physics education research (PER) provides some clear answers to my guiding question. As a result, our students are actively engaged in constructing physics concepts and explaining their ideas to one another. A typical lesson takes the form of a guided-inquiry investigation that follows Arons' constructivist approach of "idea first, name second, and math third"\(^5\). Inquiry-based learning is very time-intensive, so traditional lectures and laboratories are all but eliminated. A single investigation\(^6\) weaves together empirical explorations, searching for patterns, concept development, testing, refining and problem solving into a logical flow. In approaching the curriculum, we favour depth over breadth. To allow this, some topics such as modern physics and light are largely omitted. Research suggests this type of deep focus does not handicap but rather benefits students in their future studies\(^7\). Students typically conduct all their work in groups of three, changing after every major unit. We emphasize problem solving using a modified version of Knight's solution process\(^8\), which has a strong emphasis on multiple representations. Grade 12 students face regular problem-solving challenges using an adaptation of Heller and Heller's Cooperative Group Problem Solving\(^9\) with an added empirical component. Homework in grade 12 also involves a daily summary and self-reflection. We have examined each element of traditional teaching and attempted to redesign them to make the best possible use of our time in class and students' efforts at home.

THE ROLES OF STUDENTS AND TEACHERS

Learning in this new environment can lead students and teachers into uncharted educational territory. Students are no longer passively receiving information to be regurgitated later. Instead, they are measuring, thinking, supposing, testing, collaborating and explaining for almost 70 minutes each day. They need to be much more curious, helpful, articulate, and responsible than ever before—traits that demand much of each student and draw upon skills that are often not explicitly taught. Students are successful partly because they receive careful training in these skills during the first week of the course: students learn how our groups are structured and what their individual responsibilities are; they practice evaluating responses to questions to acquaint them with the writing standards to which they will be held. Students are provided with training and exemplars for cooperative group problem solving, homework problem solving, and self-reflections—everything they are expected to do—making the path to success as clear as possible.

The role of the teacher is changed even more radically than that of the student. In a typical class, I start with a five minute discussion that sets the framework for the day's investigation. As students work, I circulate and interview the groups to check on their progress and probe their understanding. When common difficulties arise or an important stage in the investigation is reached I might stop the groups and begin a short class discussion, arrange...
student presentations or pose a conceptual multiple-choice question using the Peer Instruction technique\(^\text{[10]}\). I set the pace of the class, giving students enough time to wrestle with the ideas while keeping things moving to reduce frustration and distraction. There is little or no unstructured time in class: every minute is valuable and can be used to maximize learning. Of course, the teacher’s role is never complete without ‘marking.’ I evaluate the work of one or two randomly chosen groups each class and on unannounced occasions check the whole class for homework completion. Students’ individual work on tests is heavily weighted to encourage individual responsibility in group work.

**MAKING IT WORK: GENERATING BUY-IN**

I have found that students can be reluctant to embrace a new style of learning and can become annoyed when pushed out of their comfortable routines. I believe good classroom morale and a high level of student commitment are crucial to the success of a reformed physics classroom. To overcome students’ concerns, the training process involves helping students understand why it is necessary to change how they learn physics and why the new techniques are better. We show our new students data from conceptual surveys demonstrating how much more students at York Mills learn compared to students in a traditional class. Adjusting to working in groups requires a considerable shift in student attitudes from a fairly selfish disposition (“my work improves my understanding”) to one of caring for the understanding of others. This shift needs to be carefully motivated. Both strong and weak students benefit from learning socially—the strong are encouraged to explain and justify their ideas and the weak get immediate tutoring and guidance. We do not evaluate group performance. Instead, students periodically evaluate themselves and their group, reflecting on what might be done to improve. Ideally, students feel that they are part of a learning team within a classroom culture of success, where both their peers and teacher care about their understanding and where every task has value and meaning.

**MEASUREMENTS OF SUCCESS**

After each course was established, I began to collect data from conceptual and attitudinal surveys. Results from grade 12 on the Force Concept Inventory (FCI)\(^\text{[11]}\) showed normalized gains and post-test scores that rival some of the best in the research literature. This fall was the first time that all our grade 12 students have been trained in our reformed grade 11 program. We observed a statistically significant improvement in their FCI pre-test scores (student-t 0.03, Cohen’s d 0.34).

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</tbody>
</table>

We have also run post-instruction surveys for: kinematic graphs (TUG-K), mechanical waves (MWCS) and DC circuits (DIRECT) for grade 11; and energy and momentum (EMCS) and electric and magnetic fields (CSEM) for grade 12. For each of these surveys, our class averages exceed those of most first year university classes.

The Colorado Learning Attitudes about Science Survey (CLASS)\(^\text{[12]}\) measures how “expert-like” the attitudes of students are concerning the nature of science and the process of learning physics. Traditional physics instruction and even many reformed programs tend to bring about a decrease in CLASS scores, meaning attitudes become less expert-like\(^\text{[12]}\). We ran this survey for the first time this past spring and results for grade 12 show significant improvements overall and in most sub-categories of the survey. Notably, grade 12 students experienced a large gain in problem solving confidence even though homework is never taken up in class. We also observed a significant increase in the CLASS category for personal interest amongst female grade 11 students.
Visitors to our physics classes routinely comment on how focused the students are for the entire 70 minute class. The guided inquiry activities are designed to be thought-provoking and enjoyable, but I suspect much of the students’ motivation is derived from the process of building knowledge and successfully testing their own understanding. There are often cries of “Whoa!” and “Yesss!” as groups succeed in the physical tests of our problem-solving challenges. Enrollment in the physics program has been strong: our school population is declining, but physics enrollment remains steady. In grade 12, we have a low course attrition of about three students per class of 30—even struggling students stick with the course. The vibrant classroom environment and levels of student engagement were enough to convince me that the reformed program was a success. I hope that these observations and the survey data may convince others that this is an educational approach worth exploring.

A REPRODUCIBLE MODEL

This program may serve well as a model for physics instruction in other high schools. Last year, two other teachers at York Mills were trained and have run the reformed courses successfully. Data from their classes show strong learning gains. This program has also been adopted by a number of other teachers in Ontario and across Canada. Their anecdotal reports closely match my own observations of student engagement and interest. Recent FCI results from one adoptive Toronto high school showed a strong gain of 0.41. Complete electronic resources for the courses are available online to allow for easy adoption and adaptation[6].

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Traditional post-secondary classrooms are designed to facilitate the transfer of information from expert to novice: there’s a place at the front for the teacher to talk, and there are places for the students to listen – usually in rows of front-facing desks.

Modern classrooms, however, can – and should – do much more.

Instead of being passive, teacher-centred spaces, classrooms should be designed with student-centred, active-learning strategies in mind. Decades of physics education research have shown that active-learning instruction can significantly improve meaningful learning in comparison to traditional lecture-based instruction in physics[1].

So, what does a modern student-centred active-learning classroom look like? How can classroom design help maximize active-learning strategies and how can classrooms make the most of the affordances that modern technologies provide?

**HOW DO WE LEARN? THE CONSTRUCTIVIST MODEL**

Learning is an active, contextualized process that builds on prior knowledge[2]. It is done through social interactions and is mediated by tools[3]. Learning is therefore not simply a matter of transferring knowledge from expert to novice – it is a process of constructing one’s own understanding. To learn physics is to actively engage in using the conceptual tools and ways of thinking that define the field of physics.

**FROM ABSORBING TO CONSTRUCTING: A NEW DESIGN PARADIGM**

Teaching should be about providing opportunities and support for meaningful learning. Class time should be spent on getting students to engage in purposefully designed activities that leverage the affordances of social interactions across a variety of levels (including pairs, small groups and the whole class), and in order to make it all work the teacher needs to assess and manage many things, including metacognitive processes, student and group self-regulation, and collaborative learning strategies. Classroom design can help with all of this.

If we accept that students construct knowledge through interactions with each other, their teacher and the subject material, and if both the teacher and student roles in the classroom expand, what elements are important in a new paradigm for classroom design? Several key elements include:

- The central focus of the classroom should not be on the teacher but on the social interactions through which knowledge is best constructed, including peer-to-peer interactions and novice-to-expert interactions at various levels.
- The most powerful tools for creating, modifying and manipulating artifacts of knowledge should be put into the hands of the students and not just the teacher.
- The classroom setup should facilitate the teacher’s ability to interact with students and their work, and it should provide the teacher with powerful yet easy-to-use tools to assess and manage the work being done.

**SOME EXAMPLES**

Over the last two decades, new classroom designs have emerged that meet many of the design features listed above. Among the most popular are the SCALE-UP classrooms (Student-Centered Active Learning Environment with Upside-down Pedagogies) that were pioneered at North Carolina State University (http://scaleup.ncsu.edu). Since the early 1990s these classrooms have steadily grown in popularity, as has the evidence of their effectiveness[4,5], which includes significant increases in conceptual understanding, improved attitudes, successful problem solving, and higher success rates, particularly for females and minorities.

**SUMMARY**

This article explores active learning classroom design and highlights a made-in-Canada design that is unique in its use of interactive whiteboard technology to promote co-operative group work.
There are now more than 150 such classrooms across the United States, including the much-talked-about spin-off TEAL classrooms (Technology Enabled Active Learning) at M.I.T. and in Canada at McGill, UBC, McMaster and Simon Fraser University, to name a few. Typically, these classrooms feature round tables where nine students work collaboratively in groups of three (each with their own personal computer on the table). In addition, around the walls of these classrooms are a mix of whiteboards for students to work on and screens to project the contents of student or teacher computers. SCALE-UP classrooms typically seat 50 to 130 students.

A newer variant of Active Learning Classrooms has recently been developed at Dawson College in Montreal by the authors. In our case, we sought to use the lessons of active learning classroom research to enhance collaborative group work in smaller classrooms (30–40 students) by re-designing the tables and providing multi-touch SMART Boards (http://smarttech.com/smartboard) for each student group (along with one for the teacher). SMART Boards offer unique affordances when it comes to collaborative group work and in particular, they offer powerful opportunities for the creation, manipulation and distribution of shared artifacts as well as the orchestration of class activities.

In order to seamlessly integrate SMART Boards with each student group without compromising interactions between peers at each table, we had to re-think the design of the student tables. Instead of large round tables, we decided to make the tables smaller and shaped like an oval with one end “pinched” smaller than the other. In order to maximize the opportunity for peer-to-peer interactions we also removed all obstacles on the tabletop. We then arranged the tables around the room in a horseshoe shape and placed the SMART Boards on the wall at the wide end of each table (See Fig. 1).

We feel that this design has many advantages:

- It allows for improved interactions between peers at each table by eliminating items from the tabletop and by bringing peers closer together.
- It eliminates personal computing devices and replaces them with a multi-touch computing device that is shared by the entire group (encourages negotiation).
- It makes the work done by groups easily visible to others, including the teacher.
- It allows for greater room between the tables, which facilitates circulation and interactions.
- It is a flexible environment that lends itself well to a variety of teaching modalities, including mini-lectures, peer instruction[6], interactive simulations (like PhETs), group work, problem solving, jigsaw activities, etc.

Unfortunately, money doesn’t grow on trees and the investment required for a technology-rich active learning classroom like ours is significant. Having said that, these costs will only decrease as interactive technologies continue to develop making such learning environments ever more affordable. What’s more, we expect to build one or more low-tech variants of our design (where student SMART Boards are replaced with whiteboards for example) that can be used in collaboration with the high-tech rooms through a flexible scheduling arrangement to improve the benefit-to-cost ratio. Importantly, we are currently conducting research to identify the effect such rooms have on teaching and learning, and while it is not the purpose of this article to report on those results, we are encouraged by the result we are getting. As has been found generally with SCALE-UP classrooms, we too are seeing increases in conceptual understanding, improved attitudes, successful problem solving, and more.

**ONE LAST THING**

It is important to emphasize that classroom design is not as important as pedagogy[7]. Active learning can be done in any...
classroom, but in a classroom that is specifically designed for it, there are richer opportunities to make the most of active learning strategies. The downside is that being an effective teacher in an active learning classroom can be very challenging. It is therefore not enough to build new classrooms without developing the expertise to use them properly. At Dawson College our development of expertise has been done (largely) through a vibrant community of practice. In weekly meetings, the teachers who use these classrooms share our successes and failures, exchange ideas, explore the active learning research and support each other as we grow.

REFERENCES

SALTISE: Bringing Pedagogical Innovations into the Physics Classroom

BY ELIZABETH S. CHARLES, NATHANIEL LASRY, AND CHRIS WHITTAKER

Empirical studies in physics education and other science disciplines show that students experience significant improvements in learning when active learning pedagogies are used\(^1\). These reports refer to changes such as deeper conceptual understanding, adoption of discipline-based thinking\(^2\) and so forth. Active learning includes approaches such as peer instruction (PI)\(^3\) and project-based learning (PBL)\(^4\); and techniques such as reflective writing\(^5\), Just-in-Time Teaching (JITT)\(^6\), and interactive lecture demonstrations\(^7\).

Nobel Laureate physicist Carl Wieman\(^8\), distinguished physics faculty members at institutions such as MIT, Harvard, and the University of Maryland, and the Quebec provincial Ministère de l’Enseignement Supérieur, Recherche, Science et Technologie (MERST)\(^9\) have all lamented the need for changes to physics and science teaching. However, this is easier said than done. Pedagogical innovations – such as those designed or investigated in physics education research – are generally situated in richly-supported environments. Adapting them to meet the needs of the day-to-day practices of the typical physics classroom is deceptively complex. Traditional professional development efforts show little lasting change partly because of the short-duration support phase\(^10\). And, fundamentally there is much yet to be understood about how research-based pedagogies must be adapted, implemented and enacted to ensure results equivalent to those reported at the experimental stages\(^11\). So how do we start to ensure feasible pedagogical change? How do we move beyond the cycles of pedagogical reform and abandonment?

**DEscribing SALTISE**

The Supporting Active Learning and Technological Innovations in Science Education (SALTISE) is a consortium whose mission is to address these questions. It owes its start to a two-year infrastructure grant from the MESRST (Quebec’s ministry of higher education) awarded to Dawson, John Abbott and Vanier Quebec colleges (Cgeps) and McGill University. This “inter-order” institutional grant drew together science faculty from these partners as well as other Montreal-area post-secondary establishments. Focused on identifying and creating mechanisms to develop and disseminate best pedagogical practices, SALTISE emphasizes the creation of local resources and local communities. Though it draws on the results of physics education research and supports small initiatives, some having conducted their own quality assurance assessments, this current initiative is not itself a research project.

**What are its goals, and how has it worked?**

The basic mandate of SALTISE is to disseminate evidence-based pedagogical approaches and build communities of practice\(^12\) that will sustain their implementation across institutions. The mechanisms of this model are much the same as scale-free networks\(^13\) that connect local communities to each other through hubs, which in turn are connected to the larger consortium. Each hub is encouraged to develop infrastructure support for initiatives of individual instructors, physics departments, and science programs. Meanwhile, the larger consortium orchestrates and coordinates with regional associations, provincial and inter-provincial science associations – e.g., the Canadian Association of Physicists (CAP), special interest group Division of Physics Education (DPE).

Since its start in 2012, SALTISE has organized talks, workshops, and guest speaker events as part of its community of practice. Many of these have been directed locally and have involved small groups of faculty at their respective college or university. Each year has culminated in an annual SALTISE conference, with keynote speakers including physicist Eric Mazur (2012), and learning scientists Manu Kapur and Jim Slotta (2013). The conferences have created a nexus, providing opportunities for educational practitioners and pedagogical researchers to...
learn from each other. In addition, these events have opened a pathway to facilitate conversations between physics instructors, physics education researchers, learning scientists and educational technology researchers.

SALTISE has also endeavoured to provide infrastructure support for the development of local resources. For instance, SALTISE allocated mini-grants to recruit new members in different institutions and help them develop or implement local pedagogical innovations. Three larger projects were led by SALTISE’s physics members: (1) the Active Learning Classroom (ALC) community of practices at Dawson and Vanier – with over 30 faculty from physics and other disciplines; (2) the Peer Learning Facilitators (PLF) – a peer mentorship project involving two introductory courses with over 100 students and six physics PLFs at McGill University; and, (3) the DALITE project – a web-based asynchronous peer instruction environment designed to facilitate learning conceptual physics – piloted in three colleges and one university with upwards of 500 first-year physics students. Each of these initiatives has conducted their own quality assurance assessment. Those results are not part of this article but will be published elsewhere.

Why is SALTISE a story for physics in Canada?

Founding members of SALTISE come from physics departments at colleges and universities in Montreal and the surrounding region. These faculty have established vibrant communities of practice at their respective institutions and they have made efforts to link SALTISE to the larger national associations such as the CAP’s Division of Physics Education. Furthermore, these faculty, who are mostly local Physics Education Researchers, have contributed much to the development of a model for changing pedagogical practice, that is, a collaboration and co-design approach that brings pedagogical research and everyday teaching together. This model promises to address the challenge in how to implement empirical results to guide how physics is taught. Additionally, they have contributed to a model of design-based research professional development: a way of encouraging instructors to participate in discipline-specific educational-research. In this way recognizing both the importance of connecting research to practice and the dialogical nature of this relationship – i.e., bi-directional and nonlinear.

What can we learn from the experiences of SALTISE?

At its core, the story of SALTISE is about how to establish a community of practice and how that community can move a vision forward. Getting started requires convincing funding agencies to buy in to a new model of pedagogy and its benefits to student success. Maintaining the momentum of the community, however, requires reinforcement of the common vision by frequent gatherings and opportunities for dialog and mutual learning. Success comes when instructor/practitioners and pedagogical researchers, working side by side as co-designers, bring to bear their disciplinary expertise to solve challenges related to learning and instruction.

Last but not least, success involves acknowledging that change takes time and money. This includes the time to design, implement, and test out solutions, as well as the time it takes to provide evidence of the benefits – i.e., the economics of the investment in change. The experience of SALTISE has shown that moving forward includes supporting instructors with time for development, exploration and investment in quality assurance – i.e., providing adequate liberation from instructional responsibilities.

Support for similar projects must come at all levels, including governments, foundations and corporations. We encourage provincial initiatives such as SALTISE as well as the development of a national initiative to bring together like-minded efforts.

REFERENCES


More than 25 years ago, Lee S. Shulman, then president of the American Educational Research Association\(^1\), challenged us to re-think how we prepare teachers through focusing on Pedagogical Content Knowledge (PCK) - the knowledge of content and content-specific pedagogies. Shulman pointed out that in their attempt to incorporate generic educational research, many Teacher Education Programs suffered from the “missing paradigm” problem. They neglected the nature of the subject matter that teacher candidates were preparing to teach.

Teacher Education Programs have since tightened their entrance requirements. For example, to enter the Physics Teacher Education Program at the University of British Columbia (UBC), applicants must have a B.Sc. with a GPA of 65% or higher. At first glance, this should address the “missing” physics content knowledge problem and justify the reduced emphasis on the physics methods courses (courses dedicated to developing teacher candidates’ PCK). At UBC, out of the 60 credits of the program, only three credits are dedicated to physics methods.

Recent poor results of Canadian students’ performance in international mathematics and science tests\(^2\) challenge the separation of Content and Pedagogical Knowledge in teacher education. Evidence of science graduates’ superficial conceptual understanding\(^3\) raises further concerns about the lack of content emphasis in teacher education. Moreover, since Canadian teachers have limited access to content-specific professional development, teacher education programs should emphasize the development of teacher candidates’ PCK.

Lastly, there is a significant gap between the findings of Physics Education Research (PER)\(^4\) and current physics teaching practices. In the words of physics Nobel Laureate, Prof. Carl Wieman:

> At the K-12 level, although there are notable exceptions, the typical teacher starts out with a very weak idea of what it means to think like a scientist or engineer. Very few K-12 teachers, including many who were STEM majors, acquire sufficient domain expertise in their preparation. Hence, the typical teacher begins with very little capability to properly design the requisite learning tasks. Furthermore, their lack of content mastery, combined with a lack of pedagogical content knowledge, prevents them from properly evaluating and guiding the students’ thinking. (p. 4)

(italics added)

To improve how secondary students learn physics, we must help teacher candidates construct PER-informed PCK. The following section describes a physics methods course that was designed to help teacher candidates develop PCK through the design and implementation of PER-informed physics teaching materials.

**COURSE DESIGN AND IMPLEMENTATION**

The 3-credit physics methods course described in this paper was implemented at UBC in the fall of 2012 (N = 13 teacher candidates). All but one of them had at least a B.Sc. or B.Eng., two earned a M.Sc. or its equivalent, and one was enrolled in a concurrent Teacher Education Program. The course had one instructor (the author) and one Teaching Assistant. The purpose of the course was to help teacher candidates develop physics-related PCK. From the first day, teacher candidates were introduced to the results of PER regarding the importance of interactive engagement and active learning\(^5\). This was done using science education “classics”, such as Mazur’s Peer Instruction (PI)\(^5\), A Private Universe Project\(^6\), and relevant PER papers. These resources emphasize the
importance of active engagement and prior knowledge in science learning. Then the instructor started modeling PI\(^5\)\(^,7\) with the teacher candidates alternatively using an electronic response system (clickers) and low-tech methods such as flashcards or hand-voting\(^8\). Every correct and incorrect answer used in multiple-choice questions was analyzed from the PCK standpoint, uncovering the underlying concepts and possible student difficulties. In addition, teacher candidates were encouraged to apply the general pedagogical knowledge of Bloom’s taxonomy in cognitive domain\(^9\) to the analysis of these questions in order to ensure they promote higher-order conceptual thinking and not just information recall. Most of these questions were taken from The Mathematics and Science Teaching and Learning through Technology (MSTLTT) research-based database containing hundreds of multiple-choice physics questions\(^10\). After the teacher candidates had mastered the basic strategies for designing higher-order-thinking multiple-choice conceptual questions, they were introduced to the MSTLTT resource and were encouraged to use it.

Conceptual multiple-choice questions were used consistently during the course. While clickers were used anonymously, teacher candidates felt very comfortable “defending” their solutions. Having the answer histogram displayed motivated the group to discuss potential student difficulties and various pedagogical approaches. Moreover, as in the question displayed in Figure 2, a discussion was often followed by a research paper illuminating the pedagogy of teaching this concept\(^11\). With time, teacher candidates were asked to provide constructive feedback on the questions used in the database and design conceptual questions of their own. At the end of the course, these questions were analyzed using the PCK rubric developed by the research team. The teacher candidates were also encouraged to use conceptual questions during their practicum.

**Teacher Candidates’ Feedback and Their PCK Gain**

Teacher candidates felt overwhelmingly positive about the use of PI in the methods course. They articulated how PI helped them acquire PCK by making the often invisible physics reasoning visible. They also emphasized the importance of eliciting their own thinking and conceptual understanding while becoming cognizant of how other learners might think about the problem. PI provided a venue for them to practice thinking and reasoning about conceptual questions. Thinking simultaneously as teachers and as students in the physics methods course was also very valuable. In the words of one teacher candidate:

...I know when we did ... clicker questions in the methods class, particularly on things like electrostatics which I then taught, I definitely know that those brought out questions and ideas for me that I wouldn’t have thought of otherwise, that I then brought up with the students because I knew that it was a mistake I made (laughs) when we were going through it. So it was ... helpful in illuminating ... my own misconceptions which could then help for future teaching.

This quote shows how PI helped teacher candidates build the confidence needed to implement this pedagogy in their classrooms. Every teacher candidate reported focusing on asking pedagogically effective questions during the practicum; four teacher candidates used PI consistently during the practicum (two of them used clickers and two others used flashcards), while others reported using this pedagogy occasionally. Most of the teacher candidates drew on the questions from the MSTLTT database and other resources. Some designed their own conceptual questions.

In addition to collecting teacher candidates’ feedback and observing their practicum teaching, we analyzed the quality of their conceptual questions. We found that they gained important skills in designing conceptual questions addressing student conceptual difficulties.

**CONCLUSIONS**

This paper shows how PER can be introduced in a physics methods course to help teacher candidates build PCK. Modeling research-based physics pedagogy in a methods course
helped teacher candidates experience research-inspired pedagogy both as students and as teachers and opened them for implementing it in their classrooms. PER-informed pedagogy was valued by teacher candidates. Using it in physics methods courses is critical in helping bridge the gap between PER results and K-12 physics teaching practices, which is necessary for educating well-prepared, motivated and scientifically literate citizens.

REFERENCES

Developing Pedagogical Content Knowledge for Pre-service Physics Teachers: Exploring Physics Education Research in Practice

BY SHAWN MICHAEL BULLOCK

Each semester I puzzle over the ways in which I might engage future physics teachers with Physics Education Research (PER) literature during the “curriculum methods” that I teach as a part of our teacher education program. Despite many important advances that have been made by physics education researchers and the gradual dissemination of ideas like peer instruction\(^1\), interactive lecture demonstrations\(^2\), and the importance of identifying students’ prior assumptions about physics concepts\(^3\), the implementation of PER approaches can seem daunting and/or unfeasible to future physics teachers. In my experience, future physics teachers often struggle initially to transform the conclusions from PER to practical approaches to teaching secondary school students.

This article describes the use of pedagogical content knowledge (PCK)\(^4\) and Content Representation (CoRe)\(^5\) to\(^7\) to engage physics teacher candidates in thinking about how conclusions from PER can be applied to their work as physics teachers. PCK is a heuristic for thinking about the unique nature of physics teachers’ professional knowledge. CoRe is an approach to teaching teachers that may assist future physics teachers in developing their pedagogical content knowledge and making links between PER and their practice as secondary school teachers.

Pedagogical content knowledge is an appealing concept. It names what many people tacitly believe: that neither knowledge of subject matter nor knowledge of general pedagogical principles is sufficient to successfully teach a given subject. Shulman\(^4\) originally argued that PCK “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching . . . The particular form of content knowledge that embodies the aspects of content most germane to its teachability” (p. 9).

Shulman’s concept of PCK was the catalyst for a vibrant and hotly debated set of research programs pursued by science education researchers all over the world. In an article published just over 10 years after Shulman’s original article, van Driel, Verloop, and de Vos\(^8\) offered an important discussion of the potential value of research on PCK. In particular, they called attention to the fact that the early years of research in PCK “focused on the nature and the development of PCK, rather than investigating science teachers’ PCK with respect to specific topics”\(^8\) (p. 690). Their research identified two major purposes for research in PCK: An increased understanding of how science teachers “transform subject-matter knowledge in relation to student learning”\(^8\) (p. 691) and, germane to this paper, the ability to use such understandings explicitly within science teacher education contexts.

Despite such promising avenues of research, PCK remains highly enigmatic in science education research. Nonetheless many remain convinced that PCK is “one way of opening up new possibilities for looking into, and better understanding the skills, knowledge and ability of expert teachers”\(^9\) (p. 1277). I had personally found PCK to be a challenging construct, potentially only of value for theorizing about physics teachers’ knowledge of teaching, until I re-encountered the idea of Content Representation (CoRe) in work by Nilsson and Loughran\(^6\).

CONTENT REPRESENTATION

A CoRe\(^5\)\(^7\) is a pedagogical technique designed to help science teachers understand K-12 students’ prior assumptions about scientific concepts and to design lessons that incorporate research-based ideas about the ways in which prior assumptions might be challenged in a productive way within a science classroom. The output is often some kind of document (I have used both narrative documents and documents created with presentation software) that

Summary

This article summarizes my attempts to help pre-service physics teachers in my curriculum methods courses develop strategies for using conclusions from Physics Education Research in their future work as secondary school teachers.
reflects a teacher’s understanding of how they plan to teach a particular topic, taking into account things such as students’ prior knowledge, research findings, etc. They are different from traditional “lesson plans” in that they focus on how to teach a concept, rather than a plan for a particular period of time. As Nilsson and Loughran note: “Working with a CoRe can help science student teachers conceptualize their professional learning and empower them to actively develop their professional knowledge of practice in specific content”[6] (p. 124). For the past few years, I have made the CoRe approach an integral part of the way I teach future physics teachers in my curriculum methods courses. I use What Expert Teachers Do[10] and Five Easy Lessons[3] as my course texts; the former provides a general interpretation and analysis of approaches that support active-learning and the latter provides a useful synthesis of PER literature, conveniently presented according to topic. After exploring approaches such as Predict-Observe-Explain, Anticipation Guides, and Mind Maps[10] through hands-on classroom experiences, I introduce the idea of CoRe in the form of an assignment. I asked each teacher candidate to identify a concept in physics that they would be required to teach in the secondary school curriculum and to respond to the following questions (adapted and borrowed from What Expert Teachers Do, p. 46) in an electronic medium of their choice:

- A brief description of the concept you have chosen.
- A list of curriculum expectation(s) that require you teach the concept.
- What do you intend students to learn about this concept?
- What are some difficulties and/or limitations with teaching this concept?
- What do you know about students’ prior assumptions about this concept?
- What teaching procedures do you plan to use to teach your concept and why?
- What specific approaches will you use to determine whether or not students understand particular concepts?

Candidates were required to reference relevant PER literature throughout their CoRes, both in their discussion of students’ prior assumptions and in their articulation of the teaching procedures they planned to enact. Each person completed two CoRes over the semester, on two different topics. A full interpretation and analysis of data collected from candidates who agreed to have their CoRe assignments examined for this research is outside the scope of such a brief article. Physics teacher candidates were also required to do a presentation of the ideas outlined in their CoRe assignments for their classmates.

For purposes of this paper, I summarize and interpret some of the comments made by “Jennifer” (a pseudonym), a teacher candidate who elected to do a CoRe assignment on the colour of water. She linked her CoRe to Grade 11 curricular expectations on the nature of light. Her CoRe was provocatively titled “What colour is water?” In articulating what she wanted students to learn, Jennifer mentioned: 1. White light is composed of many wavelengths, 2. Water is blue because it absorbs red wavelengths, and 3. Camera filters work on the same concept of filtering out a colour. Her overarching interest was to link this concept to the use of filters in underwater photography.

During her class presentation, Jennifer made the following comments:

Most people think that water is colourless. It’s hard to argue this misconception because it seems so obvious ... the only time when you see the blue colour is for large bodies of water, and that’s when the whole “reflecting the sky” idea comes in. That’s difficult too because it’s not wrong – still bodies of water will reflect the sky – but that’s not the main contributor to why water itself is blue.

She then went on to cite comments made in a research article[11] to back up her claim that water is blue (a surprisingly contentious issue). Her teaching procedures included a Think-Pair-Share (familiar to those who are interested in Mazur’s Peer Instruction), a discrepant event by looking at pictures of tap water, a lake, and an underwater image, and a “flashlight experiment” in which students slowly add layers of cellophane to the top of a flashlight to observe what happens to the light being shone on a sheet of white paper. Jennifer believed this experiment to be usefully comparable to the problem of why water is blue, despite it often appearing to be clear. She concluded with a brief discussion of how she planned to assess students’ understanding of the concept.

CONCLUSIONS

Despite enthusiasm for the conclusions of Physics Education Research, many teacher candidates struggle to find make explicit connections between PER and their work as physics teachers. The Content Representation (CoRe) approach offers one important opportunity for future physics teachers to articulate their pedagogical content knowledge (PCK). In the above example, Jennifer not only shared her understanding of a non-trivial concept in physics; she also described specific, research-based approaches to providing students with meaningful ways to challenge their prior assumptions. This paper illustrates the utility of the CoRe approach for exploring the implications of PER for future physics teachers.

REFERENCES

FROM CERN to HIGH SCHOOLS: AN ARGUMENT FOR GREATER INVOLVEMENT OF POSTSECONDARY PHYSICS STUDENTS IN HIGH SCHOOL OUTREACH

BY MATTHEW BLUTEAU AND SVETLANA BARKANOVA

During the summer of 2012, one of the authors (Bluteau) was given the opportunity to conduct part of his Honours summer research at CERN as the result of an Institute of Particle Physics (IPP)/European Organization for Nuclear Research (CERN) Summer Student Fellowship. Subsequently, in the summer of 2013, Bluteau was provided with another unique experience by the Acadia Physics Department. He arranged outreach presentations at local Nova Scotian high schools about his time at CERN, particle physics, and physics as a career option. Naturally, there were a few questions that arose following this novel pilot project. Were the presentations effective? How important and beneficial is this type of science outreach? Where does outreach by postsecondary physics students stand within the context of outreach at Acadia University and universities across Canada?

The second question seems almost self-evident but is still important to consider. Matlock and Dick summarize the situation for science outreach in a previous Physics in Canada (PiC) article quite well: “… a scientifically literate population is an advantage for any nation, and … as the world becomes more inextricably tied to technology and the science behind it, the need for aggressive, systematic outreach becomes imperative”[1].

Evidently, science outreach by large, research institutions like CERN and the Perimeter Institute occupies a salient position in achieving adequate scientific education for the general population, but universities must also be involved.

As identified by Antimirova et al., Physics Education Research (PER) has made great progress in Canada in recent years, but PER is still under funded and researched compared to our brethren to the south[2]. Thus, although there is some literature on outreach in Canada, queries regarding the structure and organization of outreach programs in universities have not been posed frequently in the academic community[1,3–5]. Consequently, there are no established “best practices” for university outreach programs, and from our experience, outreach is largely organized in an ad hoc fashion with great variation between universities. It is precisely because of this lack of literature that we suggest a nationwide, institutional survey on outreach programs in order to get a current snapshot of the state of outreach in Canada and move towards establishing what principles of outreach programs are most efficacious. The typical questions that one would commence such an investigation with are the how and what questions; however, we aim to prove that the who question could be just as critical: who should be conducting scientific outreach in high schools? Furthermore, it will be argued that students granted the IPP/CERN Summer Student Fellowship or similar awards are in a particularly apt position to participate in physics outreach in high schools.

HIGH SCHOOL PRESENTATIONS 2013

As part of his summer employment in 2013 with Acadia University, Bluteau visited six high schools in mainland Nova Scotia to give a presentation about particle physics, the Higgs boson, physics as a major in university, and careers in physics. Statistics on careers in physics along with Bluteau’s own experiences as a research assistant at CERN and physics major were integrated into a projected presentation with graphics, animations, and oral explanations of theory that were tailored to the experience level and current taught units of the audience. However, what made these presentations truly unique in the context of
outreach at Acadia was that Bluteau took a complete leadership role in not only composing the content of the presentations but also making contacts at the high schools and organizing the presentations. This allowed Barkanova to occupy the less time-consuming role of supervising the content and progress of the presentations and also provided Bluteau with an accurate view of how outreach is conducted and organized.

We surveyed the teachers with whom we had arranged the presentations and who interacted with their students following the presentations. A summary of the survey questions and responses is displayed in Fig. 1. These questions were intended to verify the quality of the presentation itself, and we believe it is clear that the presentation was esthetically pleasing, well formatted, interesting, and contained an appropriate level of information.

Additionally, qualitative questions were used to determine if the presentation achieved its primary intention. When asked the question, Did you see a spark of interest in any of your students for physics/science?, all teachers replied in the affirmative, and one teacher noted, “I had a student tell me after the presentation that they were going to focus on physics in university.” Similarly positive responses were received for the question, Was there any impact of the presentation on any of your taught units?, with one particularly shining example: “I was currently teaching the unit on Nuclear Physics, [and]… Several times, they [my students] mentioned that they better understood the concepts because of Matt’s presentation.” Moreover, we believe that Bluteau’s personal connection to CERN enhanced the reality of possible applications of physics, allowing him to impart a more influential message.

PHYSICS STUDENTS IN HIGH SCHOOL OUTREACH

Dr. Barkanova trains physics majors in her classes to deliver presentations of various lengths and levels staring from their third year. By their fourth year, many of them are excellent presenters. This is a common practice in most Canadian universities, so it logically follows that postsecondary physics students should represent at least some of the personnel conducting physics outreach. Our proposition goes further than this; we believe that advanced undergraduate and graduate physics students (henceforth postsecondary students) should occupy a prominent role in high school physics outreach. There are three principal arguments supporting this proposition.

Firstly, postsecondary students will in all likelihood have smaller age differences between themselves and the high school audiences than would professors or instructors. Although firm empirical evidence is lacking, there are many intuitive observations that can be made about how a smaller age difference might be beneficial. Postsecondary students should theoretically be more aware of the cultural and social factors that influence current high school students since they went through the same systems themselves recently. Therefore, postsecondary students should know a high school audience the best, and knowing one’s audience is one crucial factor in delivering an effective presentation. Furthermore, a diminished age gap could also reduce any intimidation factor or perceived barriers produced by the seniority of a university professor, making students feel comfortable enough to ask questions to the presenter.

Secondly, this outreach experience is also hugely beneficial to the presenters themselves. Like suggested in an editorial of Nature Neuroscience, the upcoming generation of physicists (i.e. postsecondary students) will need to cut their teeth in public outreach at some
point in order to start the development of crucial communication skills[9]. And as mentioned in the opening paragraphs, it will be increasingly essential for future generations of physicists to use these communication skills when explaining key scientific principles to the general public and children. Overall, high school outreach should be viewed as a dual investment: an investment in current high school students as the future of our society and postsecondary students as the future generation of physicists.

Lastly, we argue that increasing the employment of postsecondary students in high school outreach will ease some of the burdens and eradicate barriers that other academics experience in this area. An informative, recent survey of biologists and physicists involved in outreach in the U.S.A. probed what these scientists identify as the key problems of current general outreach efforts[10]. The most popular problems listed by these scientists were a limited amount of time for outreach in already busy research schedules, a pervading attitude of discouragement for activities outside of research in the science academy, and the absence of established programs for facilitating contact with primary and secondary schools. However, if scientists involve students in their research, they teach and mentor these students anyway, and they know which of these students would make good “science ambassadors”. Then, with some minimal additional training, these students can organize and conduct outreach almost independently, saving their supervisor time in this area. This is especially relevant in small departments, like at Acadia, where limited staff members are already strained by a high teaching load. Furthermore, postsecondary students can employ contacts in their old high school to overcome the initial contact barrier, and it is likely these students will be more motivated to give a presentation in the area they grew up, especially in isolated locations that require significant travel time from major cities.

CONCLUSION

There are many benefits for increasing the role of postsecondary students in outreach: they are more familiar with the high school audiences, they save faculty time, and they gain valuable communication skills. Hopefully, this discussion will motivate universities to consider employing their postsecondary students for high school outreach, especially if these students have research experience. We also suggest a nationwide survey to establish best practices for university outreach programs.

ACKNOWLEDGEMENTS

Many thanks to T. Antimirova, M. Milner-Bolotin and A. Sarty for useful discussions. We are grateful to the Acadia University Faculty of Science and Physics Department for providing us with the unique privilege of conducting this pilot program, and to the IPP and NSERC for enabling M. Bluteau to conduct his honours summer research at CERN.

REFERENCES

8. The full survey responses and summary are available on the world wide web at: https://docs.google.com/spreadsheet/pub?key=0AioCe2qiUH1ndFmJbExOWm9bHPXp33ejetU1VBTWc&output=html.
Seven Principles for Upper Level Physics Courses

by Robert Hawkes

Several authors have developed principles for undergraduate education[1-3]. Principles are a well-recognized way to foster adoption of evidence supported educational approaches. While much has been written about the inadequacy of traditional physics teaching at the introductory level[4,5], less attention has been paid to upper level courses[6]. While some[7] have challenged the gains of active learning strategies in biology teaching, the benefits of interactive teaching seem established in physics at all undergraduate levels however.

Instruments such as CLASS[8] suggest that physics instruction may even reinforce novice views of physics, although possibly not when the Modeling approach is used[9]. There is little evidence of gain in expert (vs. novice) student thought patterns throughout the undergraduate program in physics[10]. Does expert thinking depend on making our courses more like the professional lives of physicists, and if so how is that achieved? We develop seven principles aimed at intermediate and upper level physics courses.

Active Learning

The majority of time should involve active learning. Integration of active learning principles can be achieved in several ways. Peer instruction[11] has been developed at the introductory level but the same principles can be used in upper level courses[12]. Collaborative learning[13] whereby a portion of instruction time involves students working together in groups with guided learning, can be applied at any level. We have found that students react positively to this approach in upper level physics courses. Some of the interactive PhETs are suitable for use above the first year level, and they have the benefit of having gone through rigorous validation[14]. As a check on how active learning your class is, have a colleague or teaching assistant act as an observer, and note at periodic intervals how many students seem highly engaged, engaged, minimally engaged or not obviously engaged. A more sophisticated and validated way to achieve this is through the Reformed Teaching Observation Protocol (RTOP)[15].

Learning Outcome Focus

There should be a clear statement of learning outcomes, and a transparent link between activities and these outcomes. While first year texts often have learning objectives, sometimes tied to self-evaluation questions[16], similar approaches are frequently overlooked in higher level courses. Everything you do in your class, lab or assignment should have a clear link to carefully considered learning objectives. Zwickl et al.[17] considered the interplay between learning goals, assessment and curriculum development for redesign of an advanced laboratory course.

Mastery

It is important that core concepts and techniques be mastered. The nature of physics, its sequential structure and quantitative precision, argues for mastery. One of the keys to the success of PSI/Keller Plan courses[18] is that students continue work on a unit until they achieve mastery, writing multiple equivalent tests. In PSI the mark depends primarily on the amount of material mastered. While pure PSI is only used in a few locations, the idea of allowing students flexible time and requiring mastery could be incorporated into more conventional approaches.

Model Professional Practice

The activities in upper level physics courses should reflect the full breadth of the experiences of a working physicist. Ask departmental colleagues what they do as professional physicists (e.g. data analysis, model development, simulations, experiment design, proposal writing, communication). Then alter your course to more faithfully represent the work of a physicist. This will help students see themselves in a physics career and also encourage expert modes of thinking[8]. When possible physics students should use the same equipment and software as professional physicists.
AUTHENTICITY AND AUDIENCE

Learning activities should be as authentic as possible, and an audience beyond the instructor should be provided. Too often assigned physics problems are of the closed type with exactly all information needed provided. We must in advanced courses use open type problems\[16\], and ideally case studies. Computer based analysis of experiments that can be done both in and out of class\[19\]. Ghandi et al. [20] discuss the issue of student engagement and providing authentic research experiences. Research presentations, open houses, publishing student work, and community service learning components foster an audience. Irving and Sayre [21] found that physics students associate being able to explain ideas to others with true understanding.

CREATIVE CHALLENGE

Upper level physics courses must demonstrate that creativity is a critical part of physics. Newton, Einstein and many other physicists created arguably their most important work when they were in their early twenties. While undergraduate research will remain a primary creativity vehicle, we should seek other ways such as in-course research papers, experimental design, proposal writing, student authored multimedia, and case studies.

SENSE OF COMMUNITY

Physics learning should include collaborative experiences within a supportive community. The interesting study\[22\] of great physics programs includes a number of aspects of community building. The challenging environment implied by the other principles require a supportive environment. Li et al. [23] used focus groups to define elements of a physics community.

DISCUSSION

Fig. 1 summarizes the relationship between the seven principles. At the base are learning outcomes that define what it is students should be able to do at the end of the course. Equally important is attention to active learning strategies. Authentic experiences leading to mastery will elevate the learning. Finally the learning experience should require creativity, and take place within a supportive collaborative community. While not covered here, it is also important to rethink the content of the upper level curriculum\[24\].

One can introduce techniques in a graduated manner with only modest initial changes to a conventional course. For example, a lecture + lab format course can increase active learning by having each class ends with a collaborative learning segment. You can start with only a few open type problems or case studies. Mastery principles and flexible learning time can initially be applied to the most important topics.

Canadian physicists are remarkably innovative and creative in their professional work. We need courses that more faithfully replicate that experience.

REFERENCES

Over the past decade there has been increasing interest in the development of various types of integrated curricula for science and engineering programs [1-3]. The primary motivation for almost all such programs is the enhancement of students’ ability to integrate and apply knowledge between related disciplines, rather than regarding them as fragmented subjects to be compartmentalized. In addition, both instructors and students hope to benefit from the consistency of notation, context, and vision which should result from such team-taught, interdisciplinary approaches.

In September 2012, the Departments of Physics and Mathematics & Statistics at the University of Guelph launched a new stream of first-year courses, Integrated Mathematical and Physical Sciences (IPS*1500/1510), in which physics and calculus are team-taught. Research from education and cognitive psychology [4,5] indicates that the principal benefit of an integrated approach is a deepened learning experience. Surface learning leads students to memorize information for assessment purposes in a haphazard, non-reflective fashion. In contrast, deep learning allows students to organize and structure content into a coherent whole, relating knowledge from different disciplines.

In developing these new courses, we were also motivated by a lack of synchronization between mathematics and physics in the development of fundamental skills necessary for both disciplines. An important aim of this integrated approach was the early exposure of students to such important concepts as solving differential equations in the context of springs and pendula, or setting up and solving one-, two- and three-dimensional integrals for moments of inertia and electric fields of charge distributions. Physical sciences students benefit by learning the important mathematical tools just-in-time while the mathematics students benefit from physical scenarios providing context for their application.

First semester students entering the University of Guelph in any science major within the College of Physical and Engineering Sciences were given the choice of taking either the integrated course (IPS*1500) or the existing differentiated courses (PHYS*1000 and MATH*1200). It was felt that providing students with this choice would address concerns that the integrated course would be more intimidating. In the first offering (Fall 2012), there was a roughly even split in class sizes: 88 students completed IPS*1500 whereas 82 students completed PHYS*1000.

METHODS
The following discussion focuses in detail on the approach taken in the fall semester with IPS*1500. The winter semester course, IPS*1510, was structured in a similar fashion with content focusing on thermodynamics, integration, electrostatics, magnetism, partial derivatives, multi-dimensional integrals, waves, Taylor’s series, and spectroscopy. In both semesters the courses were team taught by one faculty member from Physics (MW) and one faculty member from Mathematics and Statistics (DA).

Course Content and Structure
The course content (atomic structure, algebra and trigonometry, forces and Newton’s laws, functions and graphing, differentiation, angular momentum and energy conservation, limits, integration, kinematics, simple harmonic motion, and special relativity) is typical of a first-semester calculus-based physics course. However, in order to enhance connections to everyday life, the course is divided into themes as follows:

Course Themes
Becoming a Scientist (Weeks 1–2) This section emphasizes the scientific method, the importance of errors and error propagation in experiments, and introduces students to basic statistical quantities.
Sports (Weeks 2–6) This theme makes use of many examples of mechanics concepts such as kinematics, forces, circular motion, and torque in sports. A calculus-based approach is used for solving problems throughout this unit.

Natural Phenomena (Weeks 6–10) An understanding and appreciation for the world and materials around us is the emphasis of this section: solar energy, fluid dynamics and the flow of water through rivers, man-made and natural materials such as steel and spider-silk, and examples of nano-materials are used to explore many important natural phenomena.

Space travel (Weeks 11–12) In this unit we explore circular motion and forces in terms of objects orbiting about one another. We also introduce the concept of special relativity, specifically time dilation, and length contraction.

Course Contact Time, Credit Weighting and Assessment
Students taking either the integrated or differentiated streams have exactly the same weekly contact hours (6 hours of lectures, 3 hours of lab, 1 hour of tutorial) and receive the same total academic credit (1.00).

There is one grade assigned at the end of the semester based on ongoing assessment throughout the integrated course. As there was much discussion at the institution around concerns for students struggling with this integrated course, frequent assessment and feedback has been incorporated, coupled with a variety of mechanisms for help. Table 1 provides the details of the final grade calculation.

### TABLE 1
THE VARIOUS ASSESSED ACTIVITIES THAT CONTRIBUTE TO THE CALCULATION OF THE FINAL GRADE.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Quizzes (9)</td>
<td>20%</td>
</tr>
<tr>
<td>Physics Quizzes (3)</td>
<td>10%</td>
</tr>
<tr>
<td>Online Homework (smartPHYSICS) (4–6)</td>
<td>5%</td>
</tr>
<tr>
<td>Case Study (computational lab) (1)</td>
<td>5%</td>
</tr>
<tr>
<td>Laboratory Experiments (5)</td>
<td>20%</td>
</tr>
<tr>
<td>Midterm 1</td>
<td>10%</td>
</tr>
<tr>
<td>Midterm 2</td>
<td>10%</td>
</tr>
<tr>
<td>Final Exam</td>
<td>20%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION
The first offering of integrated physics and mathematics at the first-year level has been a success on many levels.

Student success
We are very impressed with the performance of the first group of students in this stream. As one measure of success, the final grade breakdown from IPS*1500 is summarized in Table 2; the corresponding data from PHYS*1000 are also included from the same semester offering (Fall 2012).

From the data presented in Table 2, it is clear that the students in IPS*1500 were quite successful. The failure rate was low (1.1%) and the average final grade was 76%. Table 2 shows that a higher failure rate (7.3%) and a lower overall average (68%) were observed in PHYS*1000, values that are typical of previous offerings of PHYS*1000. We must emphasize here, however, that making direct comparisons between performance in IPS*1500 and PHYS*1000 should be done in an extremely limited fashion at this time. While the content was similar, students self-selected their courses, with the distinct possibility that more adventurous, confident students with strong physics and mathematics backgrounds chose the IPS*1500/1510 option rather than the differentiated courses. In addition, IPS*1500 was designed specifically to feature frequent assessment and feedback. We will therefore limit ourselves to concluding that, in its first offering, the integrated nature of IPS*1500 did not have a negative effect on overall student success in the course.

Synchronization of Physics and Mathematics
It was found that the integrated approach in 2012/2013 led to the instructors going further in content than had previously been achieved in the separate courses. For example, this approach allowed for a preliminary discussion of mathematical concepts typically reserved for second year, such as an introduction to partial derivatives, volume integrals, and matrix theory. It is anticipated that there will be flow-through effects on courses in second year and beyond for this cohort.

### TABLE 2
FINAL GRADE BREAKDOWN FOR THE FALL 2012 OFFERRINGS OF IPS*1500 AND PHYS*1000.

<table>
<thead>
<tr>
<th></th>
<th>IPS*1500 (88 students)</th>
<th>PHYS*1000 (82 students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A’s</td>
<td>44.3%</td>
<td>18.3%</td>
</tr>
<tr>
<td>B’s</td>
<td>29.5%</td>
<td>29.3%</td>
</tr>
<tr>
<td>C’s</td>
<td>15.9%</td>
<td>31.7%</td>
</tr>
<tr>
<td>D’s</td>
<td>9.1%</td>
<td>13.4%</td>
</tr>
<tr>
<td>F’s</td>
<td>1.1%</td>
<td>7.3%</td>
</tr>
<tr>
<td><strong>Average grade:</strong></td>
<td><strong>76%</strong></td>
<td><strong>68%</strong></td>
</tr>
</tbody>
</table>
In particular, the structure and pacing of the second year Mechanics and Electricity & Magnetism courses taken by our physics majors in 2013/2014 will likely benefit from the enhanced mathematics training provided by the IPS*1500/1510 stream. While this may suggest that students opting for the differentiated stream will be at a disadvantage in upper-year courses, the vast majority of students taking this route are in programs for which the first-year courses are the only required physics courses. Few of the students in the differentiated stream would opt to take further physics courses in their studies.

Feedback from students was encouraging. By the end of the first semester there was a sense among the first-year physical science cohort that the integrated stream was the superior option due to the course pacing, student engagement through the thematic approach, as well as the more advanced mathematical concepts introduced. The overall course evaluations were excellent and written comments were supportive of this new initiative:

"By going more in depth with the topics, I feel that I now have a better understanding of the concepts than people in an equivalent course."

"IPS remains the University’s best first year course!"

CONCLUSIONS AND FUTURE DIRECTIONS

Preliminary results from the past academic year suggest that, by connecting disciplines and giving purpose, reason and relevance to the instructional unit, the new integrated curriculum led to improved student performance. It is anticipated that the integrated thematic approach, in which students are required to make connections using higher-order thinking skills and to demonstrate an acquired knowledge and understanding through projects and performances, will continue to prove an effective mechanism to enhance student performance.

While some work has been documented focusing on the pedagogical strengths and assessment of integrated physics/math courses [1,6,7], we know of nothing in the literature that focuses on an integrated thematic approach. Given that the four corresponding differentiated courses (PHYS*1000/1010, MATH*1200/1210) have been offered in parallel, we are provided with an excellent opportunity to make careful comparisons between the two approaches. Investigating quantitative measures of the learning outcomes of the integrated and differentiated courses will be a major research initiative of ours in the coming years as we continue to track these students through their subsequent studies.

REFERENCES

In this article I describe a weekly quiz activity used in my small and medium enrolment (12–54 students) introductory physics, third-year quantum mechanics and third-year digital electronics courses.

I first describe the orchestration of the weekly quizzes and then the benefits to learners and instructors of the three key features of the quizzes: (1) the frequency of the quizzes; (2) the follow-up collaborative group component that accompanies the individually-written quiz (often called a two-stage quiz or exam); and (3) the use of quiz reflection assignments which provide an opportunity for the students to earn back lost marks while learning from their mistakes.

**ORCHESTRATION OF THE WEEKLY QUIZZES**

In this section I detail the orchestration of the weekly quiz activity, which consists of the following sequential steps:

1. Students write a quiz individually.
2. After the individually-written quizzes have been collected, students write the collaborative group portion of the quiz in groups of three or four.
3. Upon their graded quizzes being returned, students are assigned an optional quiz reflection assignment in which they can earn back lost marks for reflecting on their mistakes from the quiz.

For my implementation, quizzes were written during the lecture period and this time was broken up into two stages: a 15 to 25 minute individually-written portion, and a 10 minute follow-up collaborative group portion. A few additional minutes were also required for the transition between the two stages.

In the first stage students would write the quiz individually, which consisted of three to six multiple-choice or short-answer conceptual questions and a short problem. After the individually-written quizzes were collected, the second stage of the quiz would begin and students were asked to self-organize into groups of three or four. The group portion consisted of the same questions as the individually-written quiz, with all questions being presented as multiple-choice questions and each group answering their questions on a common IF-AT (Immediate Feedback Assessment Technique) testing form\(^1\). This is a commercially produced “scratch and reveal” form which has a single keyed answer under one of the five options for each question. Students receive confirmation that their answer is correct when a star appears where they have scratched away the waxy coating for that option. If a star does not appear for a chosen option, the student receives feedback that their initial answer was incorrect and is then able to make additional attempts to find the correct answer, with the points awarded for a correct answer being reduced for each attempt required beyond the first. When buying these forms, the manufacturer provides a variety of forms with different answer keys, thus the instructor tailors their quiz or exam to match the answer key for a given form.

Although all questions were converted to multiple-choice for the group portion, keeping non-multiple-choice question types, such as short answer and short problems, on the individually written portion allowed for partial marks to be awarded and reduced the marks which could potentially be earned through guessing on the individually-written portion. Since the groups typically did very well on the group portion, with class averages in the 90–95% range as opposed to averages on the individually written portion near 65%, guessing on the group multiple-choice questions was not seen as a large concern.

The quiz grade for an individual student was weighted 75% for the individual component and 25% for the group component, where the group component was not counted if it would have lowered that student’s quiz grade.

The quizzes were returned to the students during the next class and students were given a few days to submit a quiz reflection assignment, which allowed them to earn back half of the marks they lost on their individually-written quiz through reflection on their own errors. Instead of...
simply being asked to correct their mistakes and submit those, students were asked to complete diagnosis and generalization phases for each incorrectly answered question. The diagnosis phase asked them to identify what went wrong in their answer and the generalization phase asked them to explain how they have gained a deeper understanding of the relevant physics through the process of correcting their mistakes. For an example of a detailed handout describing these phases, see the supplemental materials in [2].

In my implementation a properly completed quiz reflection assignment would earn the student back half of their lost marks, thus a student who completed their reflection assignment and earned an initial grade of 60% on their quiz would have their grade on that quiz increased to 80%.

Although it varied from course to course, the quizzes were typically worth 20% of the final course grade compared to a combined total of 50% for the midterm and final exams. Inclusion of the group portion of the quiz and of the quiz reflection assignments could only improve a student’s quiz grade, which has the benefit of lowering the stakes of the quizzes and is likely to contribute to students’ overall positive attitude toward the quizzes.

**BENEFITS OF FREQUENT QUIZZES**

From a learning perspective, it well known that frequent testing can enhance retention relative to additional study of the material by a well-studied phenomenon known as the testing effect [3]. Additionally, recent work [4] has shown that moving from two midterm exams to thirteen weekly tests significantly reduced the self-reported student use of homework cheat sites.

From a teaching perspective, weekly quizzes can provide a more accurate picture of the current level of student understanding than would a weekly homework assignment, allowing the quizzes to be viewed as a form of formative assessment, guiding both future instruction and future student studying.

**BENEFITS OF TWO-STAGE QUIZZES**

The collaborative group portion of a two-stage quiz builds additional elements of formative assessment into what is typically a primarily summative type of assessment [5]. Following up the individually-written quiz with a collaborative group quiz offers the same type of learning benefits as Peer Instruction [6], but with an even higher level of student engagement. In my experience, the room is much more animated and the discussions more intense when I compare my observations of students writing a group quiz to those of students discussing a clicker question.

Two studies, one in Physics [7] and one in Earth Science [8], have shown that the learning which takes place in the group portion of a two-stage exam is, on average, retained when the students are re-tested two weeks or three days later, respectively.

Rieger and Heiner [9] found that 76% of the students responding to a survey in an introductory physics course (N = 123) had generally positive opinions of two-stage exams. In my own introductory physics course (N = 47), when asked how they felt the group quizzes contributed to their learning, 87% of students responded that they made “a large contribution to my learning,” as opposed to “a small contribution to my learning,” or “they don’t contribute to my learning.”

One final benefit from my implementation is that the IF-AT testing forms were used to provide the groups with immediate feedback on their answers, allowing every student to know all the correct answers upon completion of the quiz.

**BENEFITS OF REFLECTION ASSIGNMENTS**

I engage my students in quiz reflection assignments so that they will take the time to look critically at their own mistakes and reflect on the thinking that led them to their incorrect answers. Formative assessment tasks, such as these reflection assignments, have been shown to reduce the performance gap between low- and high-achievers when given a follow-up transfer problem [10].

**SUMMARY**

I have successfully used the approach to weekly quizzes described above in courses with up to 54 students. Although implementation of the quizzes reduced the weekly lecture time by 35–40 minutes, I feel that the benefits discussed in this paper outweigh that loss of lecture time. Students appreciate the approach and say that it helps them learn physics. The largest time commitment for grading was the individually-written quizzes due to the inclusion of problems and short-answer questions, but converting all questions on the individually-written quizzes to multiple-choice can minimize this time commitment. The time commitment for grading the group portion was minimal due to the IF-AT testing forms. The time commitment for grading the reflection assignments can vary from small, if you are quickly scanning them to check for an appropriate level of effort, to large if you are reading them carefully and providing detailed feedback. In large-enrolment courses, options for grading the reflection assignments include the use of appropriately trained Teaching Assistants, automatic participation marks assigned to online submissions with random spot-checks to check for appropriate effort, or online peer assessment if appropriate time is taken to train the students how to grade fairly. I believe that this entire approach to weekly quizzes can be used in large-enrolment courses with only some minor adjustments and I encourage you to try this approach in your own courses.
REFERENCES

The reasons for using Information and Communications Technology (ICT) in the classroom are the same as for any effective teaching tool: they increase student active engagement and facilitate the forging of relationships between daily life events and the subject matter at hand. In addition, there is accumulating evidence that it positively impacts on the learning of the subject matter. This is particularly relevant for teaching physics because many students perceive physics as being difficult and unrelated to their everyday lives. We report here how the Physics Department at Vanier College engages students in active learning through two distinct video creation activities: videos analyzing real-world motion and videos explaining physics concepts. However, there are ongoing questions about how best to assess the impact of these active learning activities, even though research suggests that they allow for greater student autonomy and increase student motivation and depth of understanding.

SETTING THE SCENE: A DESCRIPTION OF ACTIVE LEARNING IN A CEGEP PHYSICS CLASS

The courses implementing these activities were all first year physics courses at a General and Vocational College or Cégep (Collège d’enseignement général et professionnel). The curriculum is competency-based, so there is much interest in implementing active learning throughout the network. Examples of activities in some classes include: classic peer instruction of conceptual questions with personal response systems (clickers); on-line assignments to solve numerical based problems, but used for group problem-solving in class; analysis of PhET physics simulations; problem based learning; Immediate Feedback Assessment Technique (scratch cards) and reflective writing exercises in which students compare and contrast their understanding before and after instruction. The two video activities described here are therefore taking place in the context of other active learning activities.

ACTIVITY 1: ANALYSIS OF REAL-WORLD MOTION

In this activity, groups of students are instructed to record a real-world motion of their choosing. Examples include a car slowing to a stop or speeding up, a ball falling, a football pass, a tree branch swaying in the wind, horizontal and vertical position of pedals on a passing bicycle relative to an observer, etc. Just about any motion can be analyzed for just about any topic in introductory physics: kinematics, dynamics, circular motion, relative velocity, and energy and momentum conservation. Once the video is taken, the student uploads the video onto a computer to complete the analysis, which can be achieved in a 2-hour lab. Any number of different software and applications are designed for measuring motion. However, we use Tracker, which is free and open source. The software can track objects automatically frame-to-frame and has become more sophisticated with a modeling feature which can overlay and fit to the video motion and analyze spectral lines using the pixel intensities. The analysis of outdoor motions is sometimes difficult because the edges of the object-image can vary substantially with different lighting conditions, however in this situation, the object can be tracked manually. Once a pixel-calibration length is entered, Tracker can immediately analyze the data for velocity and acceleration, among other motion parameters. However, there is often more pedagogical value for students to export the data to a spreadsheet and do the analysis themselves. Tracker can correct for moving origins and for angular motion which is not perpendicular to the camera. This messiness of the real world can open a discussion about real-world vs. laboratory conditions.

ACTIVITY 2: VIDEO RATIONALES TO COMMUNICATE COMPLEX IDEAS

Rationales are short-written, logical explanations of why or how a phenomenon happens. Written rationales are an important metacognitive tool because the process of writing focuses the mind on planning, comprehension

**Summary**

A description of how students create short videos either to analyze motion or to explain physics concepts.
Student-generated Videos in the Physics Classroom (Lenton/Adams)

Fig. 1 A montage of different student generated videos showing Tracker files (left) as well as the front pages of some video rationales (right).

and evaluation. In this activity, students produce a video rationale to explain a concept in the course to their peers. In one form of the activity, students go outside the lab to take relevant video clips and collate them into an explanatory video. For example, students went to the Montreal Jazz Festival and took short videos as well as photos that demonstrated aspects of sound waves and waves in general. The focus is bringing examples of the real world into the classroom to explain rather than analyse. Students had to collate the clips into a story line with a sound track and voice-over. Again, there are several video-editing tools available for students to do this, including iMovie (Mac) and Windows Movie Maker (PC). The editing process can be quite time consuming, so this activity is completed at home. An extension of this idea was for students to create video rationales of very specific concepts or problem solutions, in the style of one-minute physics, that is to say using time-lapsed drawing. To facilitate this, Vanier College, in collaboration with SALTISE, a Montreal-based organization dedicated to promoting active learning in the science classroom, bought 15 graphical tablets for students to use. Graphical tablets enable users to draw and write on a pad (like a large mouse-pad), while digitizing the input. This makes it much easier for students to create a short animation sequence. First, students develop a story board mapping out individual slides and also a script for what they want to say. This process is done in collaboration with the teacher. Then, they draw out each slide. To get the time-lapse feel, students use presentation software (Powerpoint or equivalent) to prepare the slides. They can create a sequence of slides with small changes to each one and incorporate animation features from the software to produce the “one minute” feel for the presentation. Finally they record the presentation with voice-over using Camtasia Studio, a software for creating video tutorials. For videos shorter than 5 minutes, Jing is a free alternative.

Assessment, Measurements and Impact

For both these activities, the process of creating the videos, the interaction between students themselves and between the students and the teachers is more important than the end product. The students were not only assessed on the correctness of the physics analysis or the video content, but also on the level of in-class engagement and creativity in the production. The videos and analysis were presented in class and peers had the chance to comment and discuss all aspects of the video (see Fig. 1).

However, as teachers/researchers we also look for more global impacts. Is it worthwhile doing these activities? Is there a demonstrable increase in understanding? These questions are part of on-going questions in the active learning community about how to appropriately assess active learning. We are also using other measures to assess the impact of these activities. One is student concept mapping over the semester. Increasing concept hierarchy and links between real-world examples and physics concepts are important markers. In addition, we measure intrinsic and extrinsic motivation using a modified version of the Academic Motivation Scale. We do see positive changes in student motivation (data reported elsewhere). In particular, we observe that a subset of students has large increases in motivation in active learning classes. This fits a pattern that can be observed in the literature: one of the main values of these activities is that they increase student motivation and engagement. This is an important observation because strong motivation is the key for strong performance.

References

8. One-minute Physics, Available at: http://www.youtube.com/user/minutephysics.
A large fraction of students completing introductory university physics courses do not plan further studies in physics. Many enrol to meet program requirements, or to prepare for standardized exams (e.g. MCAT). While tremendous gains have been made at better serving such students in the classroom, many find the labs to be irrelevant to their academic and career plans. To better engage students with diverse interests, we have implemented a set of lab activities based upon the hardware and physics of magnetic resonance imaging, to accompany a one term introductory course on electricity and magnetism. In each lab session, students are guided through an exploration of one or two components of the system along with the relevant physics. In the final lab session, each group of three students assembles the components into an earth’s field magnetic resonance imaging system with which they collect NMR spectra and two-dimensional images. These labs are intended to replace the entire term’s worth of experiments (five three-hour sessions) for UBC’s PHYS 102.

The theme of the first lab is electric circuits. After short exercises to investigate Ohm’s law with DC and AC voltage sources, students study the components of the MRI receiver. They measure the frequency dependencies of the gains of the amplifier and band-pass filter. These measurements stimulate a qualitative discussion of frequency versus time domain.

EQUIPMENT AND ACTIVITIES
The equipment used is based upon a low-cost Earth’s field NMR spectrometer that was inspired by a system developed to study sea ice in Antarctica. Fig. 1 shows the system’s components. Although commercial Earth’s field MRI systems are available, ours has several advantages. Most important is that the system is packaged to allow students’ access to each component individually. For example, the receiver is packaged into two discrete (identical) amplifiers and a band-pass filter. Each of these boxes contains a single op-amp. A second advantage is cost. We have constructed 18 complete systems with a total hardware and assembly budget of ~$40,000, not including some pre-existing equipment (computers, DC power supplies, multimeters). A third advantage is that as we gain experience with the new lab activities and equipment, we can upgrade, add, or modify components individually, as required.

The second session focuses on transmit and control components. An Arduino microcontroller forms the ‘brain’ of our system, controlling other components, generating audio-frequency pulses, and measuring voltage signals with its onboard analog-to-digital convertor. Much of this session is spent performing introductory programming tasks and exploring the capabilities required for the MRI experiments. A daughterboard for the Arduino provides a potentiometer and eight LEDs to allow the students to interact with their programs. The Arduino is then connected to the transmitter which performs an analog subtraction of two digital logic signals, then low pass filters and buffers the output. The students explore the effect of these processes with various input frequencies, stimulating further discussion of the relationships between frequency and time domains.

The third session explores magnetism and induction. Students characterize the magnetic field from a permanent magnet, the field from a solenoid (the polarization coil), and the Earth’s field. They then connect the transmit/receive coil to one of the amplifiers and the Arduino data acquisition system to study induction. A permanent magnet mounted to a spinning top induces readily observable...
signals and provides a macroscopic analog for the source of the NMR signals.

In the fourth session, we focus on reactive circuit components. Students explore the relationships between voltage and current in an inductor (the transmit/receive coil) and in a capacitor (the tune capacitor). They build and study the LC series resonant circuit that is used to receive NMR signals.

For the final session, only two components remain to be introduced: a gradient coil assembly that allows application of magnetic field gradients, and a current-supply unit to power it. The students assemble their complete system and perform pulsed NMR measurements to find the resonance frequency. They are guided through adjustment of the gradient currents to optimize magnetic field homogeneity, then purposely mis-set one gradient to allow imaging. After collecting projections, images are reconstructed using filtered back-projection. An example image is shown in Fig. 1.

In order to fit within the current structure of the course, in terms of time, personnel, and space, a number of sacrifices were required. Lab skills such as analysis of experimental uncertainties are de-emphasized to make room for discussion of concepts required to understand magnetic resonance, imaging, and Fourier transforms. Sacrifices are made in the depth with which some concepts are covered. Computer simulations in pre-lab activities (using PhET simulations\[4\]) are used to fill in some of this material. Plans for the near future however are to separate the lab component of PHYS 102 into a separate course, allowing more time to treat selected topics in detail, reverse the sacrifices, and perhaps most importantly, reduce the specificity of instructions provided to the students, allowing opportunity for higher-level decision making.

**RESPONSE**

To date, the labs have been offered to three cohorts of students: a small pilot group of 12 volunteers, and sections of 33 and 41 students. Extensive feedback was collected from the initial volunteers, both to judge student response and to help refine the implementation. Student response indicated that the build-up to a cap-stone experiment provides tremendous satisfaction. In response to an interview question “What did you think of the labs overall?” student answers included: “I think it was the most engaging lab experience that I’ve had, in any kind of school, because we were building something and there was a bigger picture,” and “Loved it. I’d give it a ten,” and “It feels more satisfying than a regular lab; a regular lab just kind of ends, but this […] feels like we actually did something.”

Our primary goal was to increase the engagement of students whose interests lie outside of Physics. We are attempting to
use both the CLASS\textsuperscript{[5]} survey along with our own questionnaires to measure an effect on student attitudes. While preliminary results do not show a significant shift in CLASS results or in overall course grades, our assessments suggest some benefit to student enjoyment. Anecdotal evidence is very encouraging: many students at the final lab sessions are observed collecting photos of the apparatus and of experimental results to keep, a number have requested electronic copies of their images, and a surprising fraction (~20%) have made a point to comment in person to the instructor on the lab curriculum. In future, students will have the option to choose between these and more traditional experiments. Student demand for the option will be one indicator of success.

A secondary goal was to encourage students to consider pursuing higher level physics courses. As more students complete these lab activities and proceed through their degrees, we will be able to track whether MRI lab students enrol in further physics courses at a greater rate.

Hardware details and links to download our software may be found in\textsuperscript{[1]}; more information on the laboratory activities is available upon request.

**CONCLUSIONS**

We have implemented a set of laboratory activities based upon Earth’s field magnetic resonance imaging to accompany a one-term introductory course on electricity and magnetism. Students who have completed these activities in place of more traditional labs appear to appreciate the practical context and interconnection between the labs.

**ACKNOWLEDGEMENTS**

Financial support was provided by UBC’s Teaching and Learning Enhancement Fund and the Department of Physics and Astronomy. D. Bonn, J. O’Connor, F. Bates, P. Trochitchanovitch, M. O’Keane, J. Day, N. Holmes, E. Koster, P. Newbury, A. Rovarger, D. Chong, J. Carolan, and all the technicians in the department’s shops are thanked for their contributions.

**REFERENCES**

3. See: http://arduino.cc
PHOTONICS RESEARCH IN THE COLLEGE PHYSICS CLASSROOM – A COLLEGE AND UNIVERSITY COLLABORATION

BY RHYS ADAMS AND LAWRENCE R. CHEN

The granting agency “Fonds de recherche du Québec - Nature et technologies” (FRQNT) has recently funded three-year research projects led by college professors[1], thus giving college professors an opportunity to share their passion and research with students. In one such example, students in a Waves and Modern Physics course are presented with real-life and photonic related examples that link to the subject matter discussed in class. Afterwards, students visit university photonics laboratories where research is conducted, and observe experiments that combine the photonic related examples seen in class. Furthermore, funds are set aside to give some students a unique opportunity to assist the college professor with experiments during a paid summer research internship.

CEGEP WAVES AND MODERN PHYSICS CLASSROOM

About 400 students enter the two year pre-university science program at CEGEP Vanier College yearly. Students study mathematics, physics, chemistry and biology in order to prepare for future university studies in the fields of science, medicine and engineering. At CEGEP Vanier College, a course on Waves and Modern Physics follows one on Classical Mechanics; it precedes one on Electricity and Magnetism.

Class lectures, active learning techniques and laboratory experiments are used in order for students to understand the physics principles. Much of the subject matter in the Waves and Modern Physics course sets the foundation for studies in photonic-related fields. In particular, by discussing fiber optic telecommunication technologies, students are presented with examples that relate to their day-to-day lives (information and communication technologies) and augment the subject matter discussed in class. This is depicted in Fig. 1; key components in a fiber based communication link that relate to class content include:

- Quantization of light, energy levels, resonance and standing waves in lasers.
- Total internal reflection in optical fibers for transmitting light signals.
- Interference and grating structures, such as fiber Bragg gratings, for filtering of light signals.
- The photoelectric effect for photodetection of light.

UNIVERSITY PHOTONICS LABORATORIES VISIT

Late in the semester, the 32–35 students in the college professor’s class are invited to an afternoon visit of the photonics laboratories at McGill University. For many, this is their first time inside a university research lab. First, the students are led to an undergraduate laboratory in optics where they see demonstrations and the type of experiments that undergraduate students complete. Students observe continuous wave light from a laser being modulated, transmitted and detected. Temporal features of signals are seen on oscilloscopes, and their spectral content seen on optical spectrum analyzers (OSA). Observing OSA traces helps the students understand the notion of the frequency representation of signals and builds on their knowledge of harmonics. Observing the complex optical spectrum of a signal helps them understand the notion of the phase of signals and phasors. It can also give a “practical” perspective to what a complex number is in terms of amplitude and phase. The effects of tuning and filtering of signals are easily observed on an OSA, as is the severing and splicing of optical fiber. At each step, the professor

SUMMARY

Promoting scientific and technical research to college students is one of the goals of pre-university college education. To achieve this goal and to forge relationships between college physics and modern communication technology, photonics research is brought into the college Waves and Modern Physics classroom. And then, the class is brought to the research laboratories!
describes the phenomena, thus emphasizing the subject matter discussed in class.

The students are then given a full tour of the research facilities and have the opportunity to see and discuss the various projects with graduate students. They see both fundamental building blocks seen in class and advanced concepts applied to real-world applications, such as the development of systems that process signals for communications or enable the detection of a particular molecule for sensing applications. This exchange with the university photonics professor and graduate students also promotes discussions on electrical to optical conversions, optical amplification, optical nonlinear effects, instrumentation, etc. Moreover, it introduces the students to other fields of photonics such as optical computing, spectroscopy, bio-photonics and nanotechnology. The cross-disciplinary approach to some photonics research highlights how all the math and science courses taken in CEGEP can be interrelated; detecting and fighting cancer cells using photonics is always an enlightening experience for students.

PAID SUMMER STUDENT RESEARCH INTERNSHIPS

Most of the college professor’s experimental research is done at McGill University during the summer months; thus providing an opportunity for college students to assist with research during a paid internship. Students learn how to use sophisticated test-and-measurement instruments and gain valuable laboratory skills that will benefit them in future college and university courses.

A second year student participated in the summer 2012 research project, where the objective was to explore different microwave photonic filter (MPF) implementations; i.e. using photonics-based technologies to filter microwave and radio-frequency signals. Specifically, we investigated how the nonlinear optical process “four-wave-mixing” could be used in a reconfigurable multiple tap delay line MPF. The project demonstrated that silicon nanowires could replace nonlinear fiber without compromising the quality of the MPF response. The student’s main role in the project was to prepare text and excel files to dynamically change the settings of some photonic devices, and hence, reconfigure the MPF response. This was a team project involving a McGill University PhD student and a visiting researcher from Istanbul, Turkey. The college student’s contributions were valuable and he was a coauthor of an international photonics conference presentation[2].

The objective of the summer 2013 research project was to realize optical transmission system building blocks using silicon nanowires. Two first year college students were involved in the collaborative project that resulted in demonstrations of wavelength routing and distribution techniques, useful for data center applications, enabled by silicon nanowires. The college students were exposed to advanced modulation schemes that relied on coherent detection receivers, hence highlighting the importance of preserving the phase of signals. The students contributed in collecting and analyzing the data, and they were acknowledged in an international photonics conference presentation[3]. At the end of the internship, the college students contributed to the Waves and Modern Physics course content.
by preparing presentations on phase modulation schemes and nonlinear processes. They highlighted parts of the research project and the links to the physics discussed in class. Both students will present their work to the next Waves and Modern Physics cohort and have the opportunity to prepare a short lecture and activity for the class.

DISCUSSION

We presented how the field of photonics lends itself well to linking college Waves and Modern Physics subject matter to student’s day-to-day lives. This current initiative will be entering its third year in 2014, providing a lab tour to a third group of students; the funds allocated for the summer research internships have been used. The collaboration is expected to grow and have an even greater impact if funding is renewed for another three years. FQRNT are allocating more funds, thus providing longer summer research internships and/or providing them to more students. Other college professors involved with technical research see this experience as a positive pedagogy tool for students. So there is an increasing interest among professors, especially at CEGEP Vanier College, to pursue their own experiences similar to this one. This current collaboration may even encourage future broader collaborations between colleges and universities in Quebec. Such collaboration promotes the importance of scientific and technical research, and follows the Quebec government’s recently released document outlining how research can contribute to the development of the province as a whole. It states the merits of teaching innovation and new technologies to our students, even in colleges.[4] Integrating research in and outside of the classroom can benefit students in all disciplines and in all levels of education.

REFERENCES

A “Flipped” Approach to Large-Scale First-Year Physics Labs

By Georg W. Rieger, Michael Sitwell, James Carolan, and Ido Roll

The Physics 100 course at UBC is an algebra-based course for students that did not take physics in grade 12. The enrolment is typically 750 students in three lecture sections and 17 laboratory/tutorial sections; most of the students are interested in the life-sciences. The lab component used to be a fairly typical ‘cookbook’-type lab in a bi-weekly three-hour format (alternating with the problem-solving tutorial) with a focus on enhancing conceptual understanding and on acquiring technical lab skills. In 2010 we decided to transform our labs. In part we wanted to have weekly labs and tutorials (both are now weekly 1.5 hour-long sessions) to obtain better synchronization with lecture, but the main reason was that the labs simply did not work. We observed that students often had difficulty relating their data to the theory that was clearly presented in the lab manual. Furthermore, students did not acquire a solid understanding of uncertainties, and failed to grasp the general nature of the scientific tools and methods that were the focus of the lab. This is not an uncommon situation in first-year physics labs [1-3].

An analysis of the cognitive tasks in such a standard lab shows why it is ineffective: students must figure out how to take data with unfamiliar equipment, read lengthy instructions, decide when data are good enough, plot and analyze data, manipulate data so that questions can be answered, and perform an error analysis — all in a relatively short amount of time. Typical lab experiments are therefore designed to yield ‘clean’ data that allow the students to get a specific ‘correct’ answer, such as the value of a physical constant. Specialized equipment (carts on tracks, inclined planes) makes the labs somewhat artificial, thus students do not perceive these methodologies as analytical tools that can help them make sense of the physical world.

**THE NEW LAB DESIGN**

Our new lab design focuses on *doing authentic science in the real world*. Students gain experience and confidence with conducting scientific investigations to answer questions while the outcome of an experiment is not known a priori. The overall goal of the lab is for students to be able to design and carry out an experiment, analyze the given data, determine uncertainties, and present their findings to their peers. In the first eight weeks of the term, we build up a “scientific toolbox” using inquiry activities and experiments with a focus on understanding experimental data and uncertainty. The first lab assumes very little prior knowledge and subsequent labs build on the preceding labs, thus slowly building up students’ skills from week to week. This idea of having students practice their increasingly complex lab skills over many weeks is not new [1,2], but in our implementation, lab homework (~30 minutes) connects consecutive lab sessions: students are asked to perform relatively simple experiments at home and bring their data to the next lab session, or they are asked to perform further data analysis at home which is then discussed in the next session. The homework thus ties the labs, together in a cyclic process (lab -> home -> lab). This makes classroom time available for discussions on planning (“how many data points should I take?”), data analysis, and other challenging concepts (“what are the sources of uncertainty in my experiment?”) that require peer and TA support, similarly to the ‘flipped classroom’ that increasingly replaces traditional lectures. While all experiments are performed in pairs, interaction between pairs is encouraged (and often facilitated) to promote peer feedback. The studio-physics style layout of the lab room with six students per table supports this format well. Whole-class discussions triggered by clicker questions take place at the beginning and end of each lab.

Most experiments in class rely on familiar equipment such as rulers and stopwatches. At home, students choose their own equipment (from what is typically available).
such as string and a set of keys to build a simple pendulum. The choice of equipment is given to students as part of the experimental design and is not dictated by the lab manual. We deliberately avoid complicated equipment and complex procedures and there is no explicit attempt to enhance understanding of physics concepts – the focus is on understanding the concepts of measurement, similar to the lab design reported by Redish and Hammer.\(^2\)

We believe that doing experiments at home may help relating physics to everyday life and so the last four weeks of the lab are dedicated to a final project to answer a question of their choice. Students perform an experiment at home (in pairs) with everyday equipment, analyze their data with the tools they have learned in class, and present their results to instructors and peers in form of a poster. There are two sessions to support the students in their final project before the poster session. In the first support session, proposals are discussed in terms of feasibility and appropriateness and in the second session, preliminary data is looked at and suggestions are made by peers and teaching assistants. The final project also serves as the main assessment of the lab. During the first eight weeks, students are assessed only on effort. In-class participation (clickers, worksheets) and lab homework are characterized very broadly as sufficient, borderline, or insufficient, using rubrics. We found that this assessment strategy works well; the students seem to understand that their engagement in the first half of the term is essential for success in their project.

**ARE STUDENTS LEARNING?**

As mentioned above, the final lab project serves as the main assessment of the labs. Since the project is done in pairs and at home with sufficient time, one would expect a relatively high average mark. The average project marks in 2011, 2012, and 2013 are 86%, 88%, 90%, indicating that students are performing as expected. Most students are able to decide how much data to take, how to analyze and present their data, and how to come up with reasonable error estimates.

To assess student learning more directly, we developed a data skills diagnostic test (available from the authors upon request) that tests the students on the specific scientific skills that are targeted in our lab. The test focuses on interpreting histograms, graphs, and standard deviation, drawing reasonable conclusions from given data, choosing appropriate data samples, evaluating agreement and quality of data. The test was first developed in 2010 along with the new labs. Students were contacted by e-mail 4 months after the end of the course in 2012 and were invited to fill out a voluntary online survey about the Physics 100 course and its components. Of the 158 respondents, 75% said that the labs have helped them to achieve the following goal: “learn to design and analyze experiments”, and 55% said that the project helped them achieve this goal. A quarter of the students (27%) agreed that the skills and knowledge targeted in the lab will be useful in other courses, and 20% said the same about the project. Some students commented that they did not like the focus on data skills and wanted more ‘typical’ physics experiments. Students also commented that the labs did not help them ‘learn physics’. We certainly need to find out more about our students’ attitudes to help us convince more of them why data and graphing skills are so important.

**SUMMARY AND FUTURE WORK**

We have designed and implemented labs in which students do a significant portion of the experimentation at home. In our ‘flipped’ approach, classroom time is spent on peer discussions and making sense of important concepts related to data analysis, uncertainty, and representation in graphs and histograms. We believe that our new inquiry-based labs are a significant improvement over the previous, more traditional labs that were not successful in teaching data skills. We have some evidence that students generally acquire the skills we want them to learn, but our lab diagnostic test needs further improvements to increase its sensitivity to student learning. Furthermore, the overall appreciation for our first-year labs still needs to be improved and we will conduct surveys and interviews to find out more about students’ views. This will help us make further improvements and convince more students of the value of the concepts and skills targeted in our new labs.

All lab worksheets and more details are available at http://www.phas.ubc.ca/teaching-support.

**ACKNOWLEDGEMENTS**

Support from the Carl Wieman Science Education Initiative (CWSEI) and the Department of Physics and Astronomy at UBC is gratefully acknowledged.
REFERENCES

The Canadian Association of Physicists launched the first Art of Physics Competition at their 1992 Annual Congress in Windsor, Ontario. The aim of the competition is to stimulate interest, especially among non-scientists, in some of the captivating imagery associated with physics. The challenge is to capture photographically a beautiful or unusual physics phenomenon and explain it in less than 200 words in terms that everyone can understand. The winning entries, plus some selected entries from previous years, will be displayed annually at the CAP Congress.

RESULTS OF THE 2014 COMPETITION

“A Myopic Perspective of the Sunrise” by Shalini Iyer, Emery Collegiate Institute, North York, Ontario
1st Prize, High School/CEGEP Class Project Category / 1er prix, catégorie projets scolaires au niveau secondaire ou CEGEP.

“Vibrating Speaker Illusion” by Hira Jamal
Emery Collegiate Institute, North York, Ontario
2nd Prize, High School/CEGEP Class Project Category / 2e prix, catégorie projets scolaires au niveau secondaire ou CEGEP.

L’Association canadienne des physiciens et physiciennes a lancé son premier concours, l’Art de la physique, lors de son congrès annuel de 1992, à Windsor, Ontario. Ce concours cherche à intéresser les gens, spécialement les profanes, à la fascinante imagerie de la physique. Le défi est de photographe un phénomène physique époustouflant, ou particulier, et de rédiger un court texte explicatif, de moins de deux cents mots, en termes très simples, à la portée de tous. Les soumissions gagnantes, et quelques soumissions des années passées, seront exposées au congrès annuel de l’ACP.

RÉSULTATS DU CONCOURS 2014

“Vibrating Speaker Illusion” by Hira Jamal
Emery Collegiate Institute, North York, Ontario
2nd Prize, High School/CEGEP Class Project Category / 2e prix, catégorie projets scolaires au niveau secondaire ou CEGEP.
2014 MEDALS AND AWARDEES

“The Displacement Log” by Nathaniel Andrade and Amir Haniff
Emery Collegiate Institute, North York, Ontario
1st prize, High School/ CÉGEP Individual Category / 1er prix, Catégorie projet individuel au niveau secondaire ou CÉGEP.

“Magnetic Fields” by Mulan Ramani
Port Moody Secondary School, Port Moody, British Columbia
3rd prize, High School/ CÉGEP Individual Category / 3e prix, Catégorie projet individuel au niveau secondaire ou CÉGEP.

“Reflection of the Sun” by Zeyneb Erdil
Nile Academy, North York, Ontario
2nd prize, High School/ CÉGEP Individual Category / 2e prix, Catégorie projet individuel au niveau secondaire ou CÉGEP.

“Glass Fireworks” by Amit Rambaran
Emery Collegiate Institute, North York, Ontario
Honourable Mention, High School/ CÉGEP Individual Category / Mention honorable, Catégorie projet individuel au niveau secondaire ou CÉGEP.
“Biréfringence” by Richard Germain, Terrasse-Vaudreuil, QC
1st Prize, Open Category / 1er prix, Catégorie Ouvert à tous.

“Arctic Ice Crystals over Yellowknife” by Wayne Hocking, London, ON
2nd Prize, Open Category / 2e prix, Catégorie Ouvert à tous.

“Aurore boréale” by Richard Germain, Terrasse-Vaudreuil, QC
3rd Prize, Open Category / 3e prix, Catégorie Ouvert à tous.

Visit http://www.cap.ca/aop/art.html to read the accompanying description of each picture.
Visitez le http://www.cap.ca/aop/art.html pour lire la description qui accompagne chacune des photos.
CAP FOUNDATION (CAPF) – Board of Directors’ Annual Report 2013

ABOUT THE CAP FOUNDATION

The CAP Foundation is a registered charity administered by a Board of Directors elected by the CAP Executive. Income from donors and corporate sponsors, supplemented by targeted fund raising campaigns, is allocated to key activities in education and outreach undertaken in support of Canadian Physics.

ACTIVITIES

A significant fraction of the CAP’s ongoing major activities in education and outreach are administered and supported by CAPF, assisted by targeted fundraising efforts and a contribution from the CAP General Fund. A summary of the significant activities for 2013 follows.

Stoicheff Scholarship

This scholarship was established in 2012 in the memory of Dr. Boris Stoicheff, an internationally renowned laser spectroscopist who also served as President of the CAP (1983-84) and the Optical Society of America (OSA) (1976). An endowment fund for this award, currently valued at just over $60,000, is administered by the CAPF. The awarding of the scholarship alternates each year between the CAP-CAPF and OSA-OSAF, with the host country allocating a $3,000 scholarship to an outstanding graduate student who has demonstrated both research excellence and significant service to the optics or physics community. The 2013 scholarship was administered by the OSA-OSAF and was awarded to Yanhui Zhao at Penn State University.

Undergraduate Lecture Tour

The national Undergraduate Lecture Tour is the largest program under the aegis of the CAPF. Costs

EXECUTIVE SUMMARY

2013 was the year in which the CAP Foundation was born. This organization replaces the Educational Trust Fund, which was dissolved in May 2013. It represents an exciting new opportunity for the CAP and for Canadian Physics.

CAPF, or CAPF, had as its first task taking on both the financial assets and the administrative responsibilities of the old ETF. The Board was constituted at the CAP Congress in 2013, and currently consists of five elected members and two ex-officio members. A set of By-laws was drawn up in accordance with the new Canada Not-for-Profit Corporations Act, and the new Board set to work in June 2013.

CAPF’s immediate tasks were the support of the 2013 CAM Graduate Student conference, held at the University of Waterloo in August 2013, managing the Stoicheff endowment fund which supports the bi-annual Stoicheff Memorial Graduate Student Scholarship, and overseeing the 2014 CAP lecture tour and the 2014 CAP awards program for Excellence in High School/CEGEP Physics Teaching which is in its fourth successful year.

We are grateful to the many donors who have made commitments to support these activities, as well as the manifold hours of time and effort contributed by individual CAP members and the CAP Executive and staff that make it all possible. Students and educators alike are inspired and encouraged by the activities of CAPF to reach high goals in the research, teaching, and learning of physics in Canada.

The Board has been holding meetings every six weeks to develop a broad vision for the promotion and support of Canadian Physics. We have exciting plans in development, and look forward to sharing them with you in the future.

Board of Directors for May 2013–June 2014

(bios of the Board of Directors can be found on the CAP website at http://www.cap.ca/en/capf)

Robert Mann, P.Phys U. Waterloo (Chair)
J. Michael Roney, P.Phys U. Victoria (Vice-Chair)
John Reid Retired (Secretary)
Brigitte Vachon McGill U.
Tim Meyer TRIUMF

The CAPF Treasurer is David Lockwood from NRC; the Executive Manager is Francine Ford from the CAP.
are shared with participating Physics Departments, with additional funds to support this event raised each year in collaboration with industry, government and the CAP as appropriate. The 2013 tour consisted of 49 lectures in nearly every physics department in Canada.

**Prizes and Awards**

Over 800 students participated in CAP prize exam competitions at both the high school and university level in 2013. The top three students for the University Prize Exam were Bailey Gu from the University of Waterloo and Brian Bi and Chao Wang, both from the University of Toronto. Award recipients and other details can all be obtained at http://www.cap.ca/en/activities/medals-and-awards/prizes-students.

The CAP Award for Excellence in Teaching High School/CEGEP Physics entered its fourth year. The award is sponsored at the national level by the CAP, TRIUMF, Perimeter Institute, the Institute of Particle Physics, and Nelson Education, and at the regional level by the BC Innovation Council and the Association of Professional Engineers and Geoscientists of BC. Five outstanding teachers across Canada received this award, and one was selected to go to the Large Hadron Collider at CERN to participate in a special international workshop for high school teachers. A report on the workshop was included in the 2013 Vol. 69, No. 3-4 issue of *Physics in Canada*. Our congratulations to these outstanding individuals! This award is being renewed for an additional three years with continued support from the CAP, TRIUMF, the Perimeter Institute, and Nelson Education.

**Conference Support**

Over 70 students attended the Canadian Undergraduate Physics Conference (CUPC) held at McMaster University in October 2013. CAPF provided financial support to assist student participants attending the conference.

The 6th Canada-America-Mexico Graduate Student Conference (CAM) was held at the University of Waterloo, August 15-18, 2013. Focusing on research done by graduate students, and featuring plenary contributions from established scientists, the conference was a big success. It provides an outstanding opportunity for students to develop professional skills, learn a broad range of physics topics, and initiate interactions across geographical borders. Further details are available at http://www.cap.ca/en/CAM2013. A report on the conference by E. O’Sullivan was published in the 2014 Vol. 70 No. 1 issue of *Physics in Canada*.

**FINANCIAL STATUS OF THE CAPF**

While 2013 was a year of considerable success for the CAPF, some challenges remain. Support through the transfer of the income received by the CAP through its Corporate memberships has fluctuated considerably over the past few years and decreased again in 2013: $9,075 in 2009, $8,250 in 2010, $10,750 in 2011, $5,250 in 2012, and $5,000 in 2013. This income is critically important to the CAPF, and CAP needs to develop an effective strategy to recruit memberships in this category.
Given that almost all of the CAPF’s income is derived from individual donations, CAP Corporate Memberships, and strategic fundraising efforts, it is essential that a coordinated strategy be developed that will improve the effectiveness and stability of this component of the CAPF.

CONCLUSION AND OUTLOOK

The past year has been one of considerable successes for the CAPF: the second Canadian-based CAM Conference, the renewal of the High School/CEGEP teaching award, and the undergraduate lecture tour; however there remains a compelling need to increase annual revenues to the CAPF in order to stabilize and further enhance our support of the CAPF core programs by building appropriate cash reserves.

We conclude this report by expressing our sincere thanks to the many individual donors and corporate / institutional sponsors who have made possible the CAPF’s support of so many important education and outreach activities in 2013. We look forward to your continued support in 2014!

“Thank you” to our 2013 donors and sponsors

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Bolton, Richard
Booth, Ivan S.
Bradley, Brian
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Brooks, Robert
Butler, Malcolm N.
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Sponsors - 2013 Undergraduate Lecture Tour

CAP’s contribution from its General Fund
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## Sponsors - 2013 High School Prize Exam

*(Supplemental Awards at Provincial Level)*

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## Sponsors - 2013 High School Teaching Awards

- Association of Professional Engineers and Geoscientists of BC
- British Columbia Innovation Council
- Nelson Education
- Perimeter Institute
- TRIUMF

## Sponsors - 2013 CERN Teachers’ Workshop

(Recipient was 2013 Award for Excellence in Teaching High School/CÉGEP Physics (Atlantic) winner Jason Jennings from Sackville High School in Lower Sackville, NS. A report on the workshop was included in the 2013 Vol. 69, No. 3–4 issue of *Physics in Canada*.)

- Institute for Particle Physics, TRIUMF, Perimeter Institute

We remind our readers that donations to the CAPF are tax deductible. Contributions may be made by anyone, at any time via the secure online form at: https://www.cap.ca/onlineforms/capfcontribution/, or during the annual membership renewal. Tax receipts will be issued for donations of $10 or more.
**Fondation de l’ACP (FACP) – Rapport annuel des directeurs 2013**

**Au sujet de la fondation de l’ACP**

La Fondation de l’ACP est un organisme de bienfaisance enregistré qui est administré par un conseil d’administration élu par le Comité exécutif de l’ACP. Le revenu provenant des donateurs et des contributeurs corporatifs, arrondi par les campagnes de souscription ciblées, sert à soutenir des activités clés pour l’enseignement et la visibilité de la physique et contribuer au rayonnement de la physique au Canada.

**Activités**

Une part significative des activités importantes que mène actuellement l’ACP pour l’enseignement et la visibilité de la physique est soutenue par la FACP, avec l’appui de collectes de fonds ciblées et d’une contribution du fonds général de l’ACP. Voici un résumé des activités importantes de 2013.

**Bourse d’études Stoicheff**

Cette bourse a été créée en 2012 à la mémoire du Dr Boris Stoicheff, un spectroscopiste laser de renommée mondiale, qui a aussi été président de l’ACP (1983-84) et de l’Optical Society of America (OSA) (1976). Un fonds de dotation pour cette bourse, d’une valeur actuelle d’un peu plus de 60 000 $, est administré par la FACP. La bourse d’études d’une valeur de 3 000 $ est décernée annuellement en alternance par l’ACP-FACP et l’OSA-OSAF à un étudiant de cycles supérieurs exceptionnel, qui s’est distingué à la fois par ses recherches et par les services rendus à la collectivité de l’optique et de la physique. La bourse 2013 était administrée par l’OSA-OSAF et a été décernée à Yanhui Zhao de Penn State University.

**Résumé**


La Fondation de l’ACP (FACP) a eu comme première tâche de reprendre les avoirs et les responsabilités administratives de l’ancien FEF. Le Conseil d’administration a été mis sur pied lors du congrès de l’ACP de 2013 et il est présentement formé de cinq membres élus et de deux membres d’office. De nouveaux réglements ont été rédigés selon la nouvelle Loi canadienne sur les organisations à but non lucratif, et le nouveau Conseil d’administration s’est mis au travail en juin 2013.

La FACP a consacré ses premiers efforts à appuyer la conférence d’étudiants diplômés CAM 2013, qui a eu lieu à l’Université de Waterloo en août 2013, à gérer le Fonds Stoicheff qui soutient la bourse commémorative bimonthuelle Stoicheff pour étudiants diplômés, et à superviser la Tournée 2014 des conférenciers de l’ACP ainsi que la médaille de l’ACP pour excellence en enseignement de la physique au secondaire et au collégial, qui connaît un grand succès depuis quatre ans.

Nous sommes reconnaissants aux nombreux donateurs qui se sont engagés à soutenir ces initiatives et apprécions toutes les heures qu’y ont consacrées les membres de l’ACP, le Comité exécutif de l’ACP ainsi que le personnel. Les activités soutenues par la FACP inspirent les étudiants et les enseignants à se dépasser dans l’apprentissage et l’enseignement ainsi que dans la recherche en physique au Canada.

Le Conseil d’administration s’est réuni à toutes les six semaines pour envisager et développer à long terme la promotion et le soutien de la physique canadienne. Nous sommes en train d’élaborer des plans passionnants, et avons bien hâte de les partager avec vous.

**Conseil d’administration mai 2013-juin 2014**

(les notices biographiques des directeurs se trouvent sur le site web de l’ACP au http://www.cap.ca/fr/facp

Robert Mann, P.Phys U. Waterloo (Président)  
J. Michael Roney, P.Phys U. Victoria (Vice-président)  
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Le trésorier de la FACP est David Lockwood du CNRC, la gestionnaire principale est Francine Ford de l’ACP.
Tournée des conférenciers
La Tournée des conférenciers est le programme le plus important de la FACP. Les coûts sont partagés avec les départements de physique participants et il faut recueillir des fonds supplémentaires chaque année en collaboration avec les partenaires de l’industrie et du gouvernement pour financer cet événement. Au cours de la Tournée de 2013, 49 conférences ont été prononcées dans presque tous les départements de physique canadiens.

Prix et distinctions


Soutien à une conférence
Plus de 70 étudiants ont pris part à la Conférence canadienne des étudiants en physique, tenue à l’Université McMaster en octobre 2013. Une contribution financière de la FACP a permis d’accorder une aide aux étudiants qui ont assisté à la conférence.

SITUATION FINANCIÈRE DU FACP
Bien que la FACP ait connu des succès considérables en 2013, des défis demeurent. Le soutien provenant du transfert de revenu reçu par l’ACP à travers les adhésions corporatives a considérablement varié au cours des dernières années et a diminué de manière significative en 2012 et à nouveau en 2013: 9 075 $ en 2009, 8 250 $ en 2010, 10 750 $ en 2011, 5 250 $ en 2012 et 5 000 $ en 2013. Ce revenu a une importance cruciale pour la FACP, et l’ACP devra développer une stratégie efficace pour recruter des membres dans cette catégorie. Étant donné que la FACP tire presque tous ses revenus de dons individuels, d’adhésions corporatives et de levées de fonds stratégiques, il est essentiel de développer une stratégie coordonnée qui améliorera l’efficacité et la stabilité de cette composante de la FACP.

CONCLUSION ET PERSPECTIVES
La FACP a connu des succès considérables au cours de l’année précédente: la deuxième conférence CAM en sol canadien, le renouvellement de la médaille d’enseignement au secondaire et au cégep et la Tournée de conférenciers. Nous avons néanmoins sérieusement besoin d’augmenter les revenus annuels de la FACP pour stabiliser et accroître notre appui aux programmes de base de la FACP, en constituant un fonds approprié.

Nous concluons ce rapport en exprimant nos remerciements sincères aux nombreux donateurs individuels et aux contributeurs corporatifs et institutionnels qui ont permis à la FACP de soutenir autant d’activités importantes sur le plan de l’enseignement et de la visibilité de la physique en 2013. Nous comptons sur votre soutien continu en 2014!

«MERCI» À NOS DONATEURS ET COMMANDITAIRES EN 2013

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(POUR L’APPUi GÉNÉRAL DE TOUTES LES ACTIVITÉS)

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Commanditaires - Tournée de Conférenciers de 2013

Contribution de l’ACP à partir du Fonds général
(associée aux adhésions départementales; voir la liste à la page 68)

Commanditaires institutionnels et corporatifs supplémentaires:
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Commanditaires - Examen du Secondaire et Collégial 2013
(Suppléments aux prix provinciaux)

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- TRIUMF

pour Terre-Neuve
- Memorial University of Newfoundland

pour le Québec
- Bishop’s University
- Concordia University
- McGill University
- Université de Sherbrooke
- Université de Montréal
- Université du Québec à Trois-Rivières

Commanditaires - Prix d’Excellence en Enseignement de la Physique au Secondaire et au Collégial 2013

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Innovation Council de la Colombie-Britannique
l’Institut Perimètre

Nelson Education Innovation Council
de la Colombie-Britannique
TRIUMF

Commanditaires - Atelier 2013 au CERN

(Le récipiendaire a été Jason Jennings de Sackville High School à Lower Sackville, NS, gagnant du prix d’excellence en enseignement de la physique au secondaire et au collégial (Atlantique) 2013) Le lecteur est invité à se reporter au numéro 3-4 (2013) de La Physique au Canada, où il trouvera un rapport sur l’atelier.

Institute for Particle Physics, TRIUMF, Perimeter Institute

BOOK REVIEW POLICY

Books may be requested from the Book Review Editor, Richard Marchand, by using the online book request form at http://www.cap.ca.

CAP members are given the first opportunity to request books. For non-members, only those residing in Canada may request a book. Requests from non-members will only be considered one month after the distribution date of the issue of Physics in Canada in which the book was published as being available (e.g. a book listed in the January-March issue of Physics in Canada will be made available to non-members at the end of April).

The Book Review Editor reserves the right to limit the number of books provided to reviewers each year. He also reserves the right to modify any submitted review for style and clarity. When wording is required, the Book Review Editor will endeavour to preserve the intended meaning and, in so doing, may find it necessary to consult the reviewer. Reviewers submit a 300–500 word review for publication in PiC and posting on the website; however, they can choose to submit a longer version for the website together with the shorter one for PiC.

LA POLITIQUE POUR LA CRITIQUE DE LIVRES

Si vous voulez faire l’évaluation critique d’un ouvrage, veuillez entrer en contact avec le responsable de la critique de livres, Richard Marchand, en utilisant le formulaire de demande électronique à http://www.cap.ca.

Les membres de l’ACP auront priorité pour les demandes de livres. Ceux qui ne sont pas membres et qui résident au Canada peuvent faire une demande de livres. Les demandes des non-membres ne seront examinées qu’un mois après la date de distribution du numéro de la Physique au Canada dans lequel le livre aura été déclaré disponible (p. ex., un livre figurant dans le numéro de janvier-mars de la Physique au Canada sera mis à la disposition des non-membres à la fin d’avril).

Le Directeur de la critique de livres se réserve le droit de limiter le nombre de livres confiés chaque année aux examinateurs. Il se réserve, en outre, le droit de modifier toute critique présentée afin d’en améliorer le style et la clarté. S’il lui faut reformuler une critique, il s’efforcera de conserver le sens voulu par l’auteur de la critique et, à cette fin, il pourra juger nécessaire de le consulter. Les critiques pour publication dans la PaC doivent être de 300 à 500 mots. Ces critiques seront aussi affichées sur le web : s’ils le désirent les examinateurs peuvent soumettre une plus longue version pour le web.

BOOKS received / LIVRES reçus

The following titles have recently been received for review. Readers are invited to write reviews, in English of French, of books of interest to them. Note that book titles followed by a [v] will be made available electronically, following the publication of a review, the reviewer will receive a hard copy directly from the publisher. Unless otherwise indicated, all prices are in Canadian dollars.

A list of all books available for review, books out for review and copies of book reviews published since 2000 are available on-line at www.cap.ca.

In addition to books listed here, readers are invited to consider writing reviews of recent publications, or comparative reviews on books in topics of interest to the physics community. This could include for example, books used for teaching and learning physics, or technical references aimed at professional researchers.


En plus des titres mentionnés ci-dessous, les lecteurs sont invités à soumettre des revues sur des ouvrages récents, ou des revues thématiques comparées sur des sujets particuliers. Celles-ci pourraient par exemple porter sur des ouvrages de nature pédagogique, ou des textes de références destinés à des professionnels.

GENERAL INTEREST


UNDERGRADUATE TEXTS


GRADUATE TEXTS AND PROCEEDINGS


BOOK REVIEW / CRITIQUES DE LIVRE

Book reviews for the following books have been received and posted to the Physics in Canada section of the CAP’s website: http://www.cap.ca. When available, the url to longer versions are listed with the book details.

Des revues critiques ont été reçues pour les livres suivants et ont été affichées dans la section “La Physique au Canada” de la page web de l’ACP: http://www.cap.ca. Quand disponible, un lien url à une critique plus longue est indiqué avec les détails du livre.


Japan and Canada were drawn into the space age, prior to Sputnik, by the desire to make space measurements during the International Geophysical Year, 1957-58. The Japanese K-6 rocket reached 60 km altitude during the IGY and by 1964 an Institute for Space and Aeronautical Science was established at Canada University. In 1959 and the first Canadian made Black Brant rockets were launched the same year. Almost in step, Canadian and Japanese space scientists collaborated over the years. But this beautifully produced book is only partly about the history, it is a contemporary description of space instrumentation, though some of it was developed over many years. It grew out of a workshop organized by the authors. The lead author, Koh-Ichiro Oyama was a pioneer in rocket instrumentation, developing a novel probe for ionospheric electron temperature measurement at University of Tokyo beginning in 1970. After his formal retirement he moved to the National Cheng Kung University in Taiwan. There, he and his colleague Chao-Zhong Cheng organized a Taiwan-Japan Workshop on Space Instruments held in 2010. The countries of authors other than from Japan are identified in this review which highlights the strong overlap with Canadian space instrumentation.

The book contains 22 articles about instruments, many of which could be flown on rockets or satellites, but 17 of these are concerned primarily with rocket flights and 5 specifically with satellite instruments. These could be further categorized as: 13 articles on measurements of the ionized atmosphere (ionosphere) and 9 on the neutral atmosphere. Except for one on plasma wave receivers the ionosphere articles are all about local (in situ) measurements. The neutral measurements are also divided between remote sensing and local, and respectively.

Beginning with the local neutral atmosphere there are two articles using electron beam excitation. Strelnikov et al. (Germany) describe a CONE instrument, essentially an ionization gauge in which the ion current is an accurate measure of the neutral density while Kurhara et al. describe the ionization and excitation of N2 into the (0,0) band of the N2+. First Negative system, producing prompt emission at 391.4 nm. By measuring the ratio of intensities of different rotational lines in the band it is possible to determine the rotational temperature, equivalent to the local kinetic temperature. This ingenious experiment was pioneered in Canada by Jaap de Leeuw of the University of Toronto Institute for Aerospace Studies (UTIAS). Iwagami and Morrow outline the use of 130 nm ultraviolet lamp radiation to excite local atomic oxygen, giving a measure of the atomic oxygen concentration. This technique is familiar to Canadians as it was pioneered at York University by Bob Young and Bill Morrow; the lamps were fabricated by Resonance Ltd. in Barrie, Morrow’s company. In another article Iwagami describes the remote sensing of NO concentration in the atmosphere, using as a spectral filter an absorption cell containing NO gas, and in a further article an instrument for determining rocket altitude from stars, as well as the measurement of Mg II ion airglow emission. Airglow measurement using filter photometers is described by Clemesha et al. (Brazil), for the observation of the O(3S) atomic
oxygen green line emission at 557.7 nm, as well as the hydroxyl and sodium airglow emissions, using both longitudinal and side-looking photometers.

Three articles are devoted to the measurement of neutral winds using rockets. The first, by Koizumi-Kurihara et al, deploys thousands of 1 μm-thick plastic foils, coated with aluminium, called chaff, which is tracked from the ground by radar. The second, by Larsen (USA) is about releases of TMA (Trimethyl aluminium) which interact with the local atomic oxygen to become chemiluminescent. The resulting trail is photographed from several different locations, allowing its position to be accurately determined in three-dimensional space, providing wind measurements. This works only at night, against a dark sky, but a technique that works in the daytime is described by Habu, in releasing of lithium from canisters through heating from thermite. The lithium is detected through its resonance red line with narrow-band filter cameras against the daytime sky background. The spectacular cloud created and tracked for as long as 40 minutes is shown as the cover photo for the book.

An article by Abe and Oyama introduces the Langmuir probe for electron density measurement, providing a history of its development in Japan, with results from rocket flights and the Japanese satellite Akebono. Sinha (India) describes probe measurements of ionospheric irregularities and Oyama and Cheng follow with the development of the electron temperature probe, invented by Kunio Hirao in the seventies, flown in over 50 rocket flights, and on the Hinotori satellite. Wakabayashi et al describe the absolute electron density probe impedance probe, attributed to Oya, but mentioning Owen Storey (who spent some time in Canada) and Keith Balmain of UTIAS. It uses RF to locate the upper hybrid plasma frequency. Piel (Germany) describes a resonance cone probe for electron density, temperature, drift speed and beam components Fang and Cheng (Taiwan) describe a retarding potential analyser (RPA) for sounding rockets. On satellites the RPA takes advantage of the ram velocity of the satellite but on rockets a different approach is required. Ishisaka describes electric field measurements from a rocket, using 1 m long tubular probes of Be-Cu, based it would seem on the Alouette/ISIS long antennas, of some 45 m. Takahashi (Brazil) describes the measurement of vector magnetic field from a rocket combined with a sun aspect sensor.

Moving specifically to satellites, Kazuma describes an energy analyzer for low energy electrons, using an MCP (multi-channel plate) intended for the LEP-e instrument on the ERG satellite, a radiation belt mission. Saito describes the All SKY-Electrostatic Analyzer low energy spectrometer for a 3-axis stabilized satellite, using scanning deflectors at the entrance and spherical/toroidal electrostatic deflectors inside. The application is MAP-PACE on the Japanese lunar orbiter Kaguya which spent 1.5 months in lunar orbit. The one Canadian contribution is by Andrew Yau et al. of the University of Calgary beginning with the Suprathermal Mass Spectrometer (SMS) flown on the Japanese Akebono satellite, developed by Brian Whalen of NRC, where a mass spectrometer was placed behind an RPA. Whalen’s Hemispherical Electrostatic Analyzer (HEA) accepted ions or electrons over a wide range of energy and 360° degrees of azimuth dispersed over an imaging detector. The resulting imaging CPA (cold plasma analyzer) was flown on the Swedish Freja satellite. The subsequent version incorporated a time-of-flight gate acting as an ion mass spectrometer, in the TPA (Thermal Plasma Analyzer) flown on the Japanese Nozomi spinning spacecraft, Japan’s first Mars mission, also used on the recently launched Canadian e-POP satellite. Matsuoka describes the development of flux gate magnetometers, specifically for the upcoming Bepi-Columbo mission to the planet Mercury. Finally, Kozima describes plasma wave receivers for satellites, referring to the pioneering work of Ron Barrington and Jack Belrose of CRC, with the Alouette I satellite, employed on the Geotail satellite, which carried three types of receivers, a swept frequency analyzer, a multichannel analyzer, and a waveform capture receiver.

An Introduction to Space Instrumentation provides a wealth of information for those involved in space instrumentation, or are just curious about it. It also reveals the many interactions between the Japanese and Canadian space programs, largely through one-on-one collaborations between the collaborating space scientists in the two countries. The author of this review would like to add recognition of the many Japanese colleagues he worked with over the years, particularly Takao Tohmatsu, who was lost to our community far too early, in 1978.

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