A NEW CDIO-BASED TRAINING PROGRAM FOR ADVANCED DEGREES IN AEROSPACE

Clément Fortin[1], Jean-Paul Lemarquis[2], Stephen Yue[3], Yaoyao Fiona Zhao[3], Michael Kokkolaras[3], Karen Packwood[1]

1 CRIAQ, Montreal, Canada
2 Bombardier Aerospace, Montreal, Canada
3 McGill University, Montreal, Canada

ABSTRACT

This paper describes a new graduate-level educational initiative based on the modified CDIO syllabus proposed by Crawley (Crawley et al, 2013) at the 2013 CDIO Annual Conference. The McGill Institute for Aerospace Engineering (MIAE), in collaboration with the Consortium for Research and Innovation in Aerospace in Québec (CRIAQ) and 4 other universities (École Polytechnique de Montréal, Concordia University, École de Technologie Supérieure and Université Laval), has designed a training program to improve the professional skills of graduate students specifically for the aerospace industry. CRIAQ is a non-profit organization that finances industry-driven collaborative research; training is a significant component of CRIAQ projects. CRIAQ's motivation to participate in this training program stems from industrial focus group results, which indicate strongly that aerospace companies are reluctant to hire graduate students, as they perceive them to lack some industry-specific professional skills.

KEYWORDS

CDIO, graduate student training, aerospace industry, industrial readiness

INTRODUCTION

Aerospace is the industry that other industries look to for a glimpse of what is on the horizon for manufacturing technologies. The highly integrated yet inter-disciplinary nature of aerospace manufacturing requires graduates with a broad knowledge of technologies, professional skills, and a system-level mindset. These requirements define two high-level yet conflicting objectives for contemporary engineering education: educating students in an increasingly broad range of technologies while simultaneously developing students' professional, interpersonal and system-building skills. Current undergraduate engineering curriculum focuses on the former. Students with advanced degrees, namely students with Master's or Ph.D. degrees, conduct research in a specialized field, but are also expected to develop the skills that will enable them to provide vision and leadership. This requires understanding of industry-specific (in this case aerospace) product development, design and manufacturing systems integration, lifecycle cost analysis and quality control.

Québec (particularly the Montréal area) is the base of several world-class aerospace industries such as Pratt & Whitney Canada, Bell Helicopter, Bombardier Aerospace, CAE, Héroux-

Devtek and many others. The total Québec aerospace sector represents about 215 companies with more than 42,500 employees and annual sales of CAD12.1 billion (Gouvernement du Québec, 2014). Québec is also the home of several top-notch educational institutions including McGill University, École Polytechnique de Montréal, Concordia University, École de Technologie Supérieure and Université Laval, who supply the aerospace industry with highly skilled and trained students. Research collaboration between the aerospace industry and academia is supported and facilitated by the non-profit Consortium for Research and Innovation in Aerospace in Québec (CRIAQ), founded in 2002 with financial support from the Québec government. CRIAQ's mission is to “increase the competitiveness of the aerospace industry and enhance the collective knowledge base in aerospace through improved education and training of students.” Its approach is to organize a research forum every two years in an open innovation format in which industry presents project ideas to universities and research institutes. From these CRIAQ is providing funding and facilitates execution of these projects by helping to set up a project teams composed of industry, universities and research institutes. Currently, CRIAQ’s membership includes 53 enterprises (of which 40 are small and medium enterprises (SMEs)), 15 universities, 6 research centers, 4 college technology transfer centers, and 11 associate members. In the past 12 years, CRIAQ has successfully initiated and sponsored 113 projects for a total project value of CAD110 million.

The CRIAQ 2022 Strategic Vision has created the CRIAQ Academy to work on the educational aspect of a new generation of graduate aerospace entrepreneurs/intrapreneurs/innovators. The principal objective is the reduction of the full integration of graduate students within companies upon graduation – from 5 to 2 years. This initiative triggered a discussion between educational institutes and the aerospace industry. The CDIO educational framework was proposed to serve as the foundation of a new training program to be embedded in regular research and academic learning programs. The aim of this new training program is to improve students' industry readiness levels (IRLs) by acquiring desired industry skills by the time they graduate. The training program is sponsored by the Natural Sciences and Engineering Research Council (NSERC) of Canada in the Collaborative Research and Training Experience (CREATE) Program. This program, which was initiated in 2008, is centered around university based research projects leading to the granting of Masters and Ph.D. degrees, as well as the training of post-doctoral fellows. In addition to the usual academic courses that are required to complete the degrees, the students and PDFs take a variety of seminars and workshops designed to transition graduates rapidly into productive employees in the aerospace industry. This particular CREATE program is based on the NSERC priority area of ‘manufacturing’. The CREATE funding, which is approximately $1.7M (Canadian) over 6 years, has been leveraged with CRIAQ brokered research project funding in order to put more than 100 HQP through this training program over the 6 year life of the program. At the end of the six years, CRIAQ will assume the operation of this training program.

The paper is organized as follows: First, the specific approach to developing the new aerospace-specific training program, based on the CDIO philosophy, is presented. The detailed training plan and activities such as workshops and short courses are then provided. Finally, evaluation criteria for reviewing and improving the proposed training program are discussed.

THE PROPOSED TRAINING PROGRAM FOR AEROSPACE ENGINEERS

Motivation: Survey Results

The conclusion of the focus group composed of leaders of industry held by CRIAQ Academy has revealed that the aerospace industry is sometimes reluctant to recruit students graduating with advanced degrees particularly those with PhD. It is instructive to note that 30 post-doctoral, 91 PhD and 103 Master's students participated in CRIAQ projects during 2011. However, this perception does not allow industry to fully benefit from the HQP trained. Moreover, all CRIAQ HQP are funded by the NSERC Collaborative Research Development (CRD) program, which means that a larger part of this Canadian investment could be used to yield a return. This situation motivated CRIAQ, McGill University and partner universities and aerospace industry representatives in Québec to develop a new training program aiming at improving graduating students' industry readiness skills. The focus of this training program is on Master's and PhD graduates.

In order to define the specific list of CREATE training program objectives, a survey (shown in Figure 1) was designed by CRIAQ in consultation with McGill University, and was sent to major aerospace industry leaders. The survey asked industry stakeholders to indicate the desired qualities of a newly graduated Master, PhD and post-doctoral student in the four categories identified in the graduate-level CDIO syllabus (Crowley et al, 2013): Disciplinary knowledge and reasoning; personal attributes (thinking, beliefs, and values); relating to others (communication and collaboration); and leading the innovation process. It should be noted that only the top two levels of CDIO syllabi were listed in this survey in order to ensure its efficiency and efficacy. The survey also asked industry stakeholders to indicate their perception of the current qualities of newly graduated PhD students. For each item listed in the survey, industry stakeholders were asked to indicate their desire in a numeric scale as following:

- 1 represents: to have experienced or been exposed to
- 2 represents: to be able to participate in and contribute to
- 3 represents: to be able to understand and explain
- 4 represents: to be skilled in the practice or implementation of
- 5 represents: to be able to lead or innovate in

The survey results for Master's-level student skills are shown in Figure 2. It is observed that interdisciplinary thinking, knowledge structure and integration (CDIO syllabus 1.4) as well as the entire category of leading the innovation process (CDIO syllabus 4) are perceived as the weakest skills possessed by Master's students. The results for post-doctoral generally have greater skills in all categories relative to Master's students and share similar trends of weakness in interdisciplinary thinking, knowledge structure and integration as well as in general leading the innovation process skills. However, too few respondents answered for that category to draw significant conclusions.

	Current Level*	Level Desired for: Master's degree	PhD degree*	End of Post-Doc (2-years)
1. DISCIPLINARY KNOWLEDGE AND REASONING *UNESCO PILLAR: LEARNING TO KNOW*				
1.1 KNOWLEDGE OF MATHEMATICS AND SCIENCES				
1.2 KNOWLEDGE OF APPLIED SCIENCE AND ENGINEERING SCIENCE				
1.3 KNOWLEDGE OF INNOVATION AND ENTREPRENEURSHIP				
1.4 INTERDISCIPLINARY THINKING, KNOWLEDGE STRUCTURE AND INTEGRATION				
1.5 KNOWLEDGE AND USE OF CONTEMPORARY METHODS AND TOOLS				
2. PERSONAL ATTRIBUTES – THINKING, BELIEFS AND VALUES *UNESCO: Learning to Be*				
2.1 COGNITION AND MODES OF REASONING				
2.2 ATTITUDES AND LEARNING				
2.3 ETHICS, EQUITY AND OTHER RESPONSIBILITIES				
3. RELATING TO OTHERS – COMMUNICATION AND COLLABORATION *UNESCO: Learning to Work With Others*				
3.1 COMMUNICATIONS				
3.2 COMMUNICATIONS IN INTERNATIONAL ENVIRONMENTS				
3.3 TEAMWORK				
3.4 COLLABORATION AND CHANGE				
4. LEADING THE INNOVATION PROCESS *UNESCO: Learning to Do*				
4.1 MAKING SENSE OF GLOBAL SOCIETAL, ENVIRONMENTAL AND BUSINESS CONTEXT				
4.2 VISIONING – INVENTING NEW TECHNOLOGIES THROUGH RESEARCH				
4.3 VISIONING – CONCEIVING AND DESIGNING SUSTAINABLE SYSTEMS				
4.4 DELIVERING ON THE VISION – IMPLEMENTING AND OPERATING				
4.5 DELIVERING ON THE VISION – ENTREPRENEURSHIP AND ENTERPRISE				

Figure 1: CDIO-based survey to identify students' skill and knowledge gaps

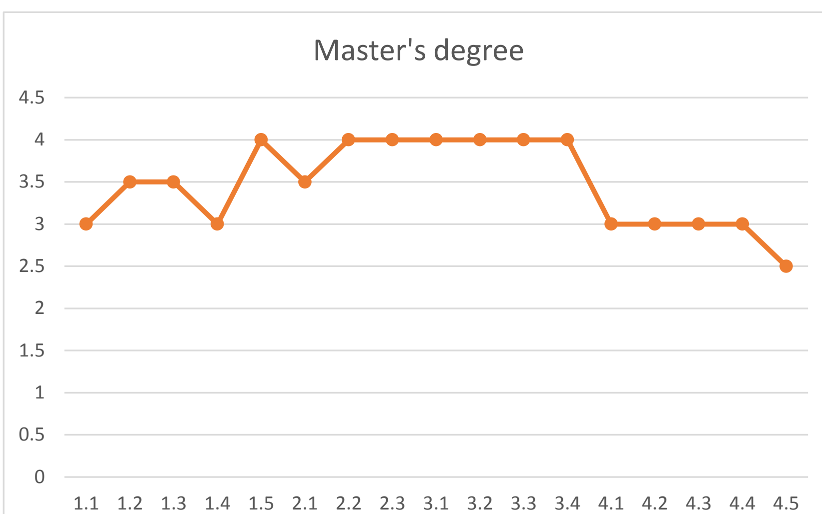

Figure 2: Survey results for current Master's degree student skills

For the sake of brevity, the survey did not ask industry stakeholders to provide feedback on desired skills for Master's and post-doctoral students because PhD students represent the largest percentage of HQP in CRIAQ projects. Thus, emphasis was given to capture and

understand the industry-desired vs. current PhD student skill levels. The survey results are shown in Figure 3.
It can be seen that industry has a uniformly high desire for all CDIO skills of a PhD graduate. However, typical PhD students possess currently lower skills than desired in the following categories:

1) Knowledge of innovation and entrepreneurship
2) Interdisciplinary thinking, knowledge structure and integration
3) Teamwork
4) Making sense of global societal, environmental and business context
5) Visioning – conceiving and designing sustainable system
6) Delivering on the vision – implementing and operation
7) Delivering on the vision – entrepreneurship and enterprise

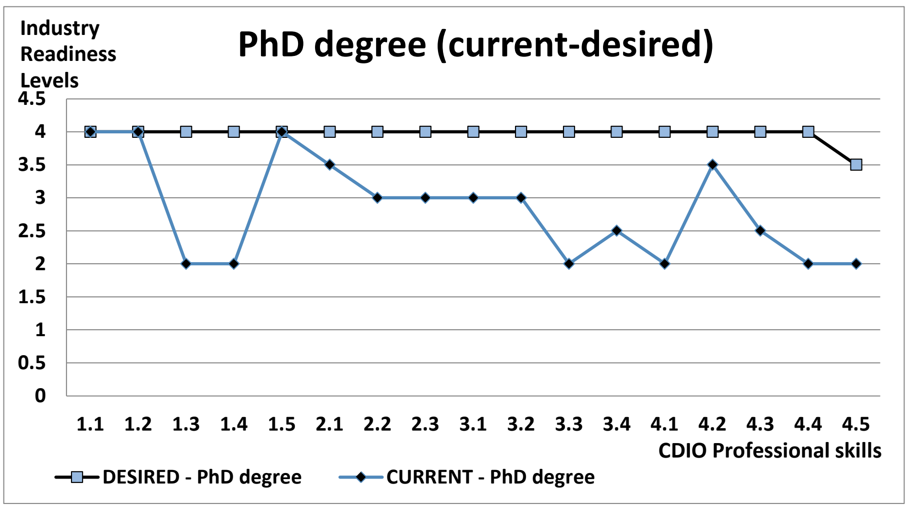

Figure 3: Survey results for current and industry-desired PhD student skills

Development and Implementation of Proposed Training Program

The survey results were then compared to the current engineering curriculum to identify potential for improvements in order to fill the identified gaps. The proposed training program is designed to implement these improvements. The desired IRLs are represented by related profiles of the modified CDIO competencies. It should be noted that traditional lecture-style teaching would not be sufficient to equip PhD students with these industry-desired skills. Thus, a unique method to train students is proposed. The uniqueness of the proposed training program lies in the close collaboration between academia and industry partners.
Trainees will be recruited by all the university partners involved in CRIAQ manufacturing projects, and will be selected based on interviews with industry to determine their level of enthusiasm and aptitude for an industrial position. All the workshops, seminars and short courses tabulated below are designed to train and prepare students to be industry ready after graduation. The program plan is described in the table below.

	A. Industrial collaborative research	**B. Workshops, short courses and seminars**	**C. Industrial research internships and mentoring**
Program components:	Well-defined research projects in various aspects of manufacturing	**Workshops** on professional development skills **Seminar series** will rotate between industry partners	**Internships:** 4-8 months paid internship in manufacturing technology and industrial practice

		Comprehensive range of **short courses** designed to improve HQP professional skills	
Undergraduate students	Undertaken during summer and continued as part of project course	Will be invited to attend seminars and workshops. Will undertake summer projects	Required as part of undergraduate program
Master's students	Thesis research project with collaboration between at least one industrial partner	Must take all compulsory workshops, seminars and short courses.	Required as part of Master's student program
PhD students and Post-doctoral fellows	Thesis research project with collaboration between at least one industrial partner	Must take all compulsory workshops, seminars and short courses with a minimum 36 hours of optional workshops/seminars and 8 optional short courses.	Required as part of PhD student program.

A. Industrial collaborative research

The training methodology begins with an appropriate research project in advanced manufacturing. Part of the training of the HQP will be the development of an industrially-holistic approach to manufacturing. It is thus a major advantage that almost all the research will be conducted as CRIAQ projects, since these are industry-driven projects, which require a minimum of two companies and two academic institutions, thus encouraging a multidisciplinary approach. These projects are designed to move the research towards practical implementation, and therefore cover many industrial aspects of the problem rather than pursuing it from only one, purely research, direction. Advanced manufacturing is a vast subject, but taking into account the needs of the aerospace industry and the expertise of the Québec universities, suitable research areas are thermomechanical processing, machining, additive manufacturing, and materials (metals, polymer composites and coatings). Moreover, the growing complexity and interconnectivity of modern aerospace engineering systems calls for a holistic approach to optimal design by means of integration with manufacturing, quality control and supply chain management. The broad and complementary expertise of the assembled research team in the areas of manufacturing, systems and processes, design theory, materials engineering, optimization and statistics will be exploited to conduct inter-disciplinary research projects that will instil system-level thinking to the trained HQP.

B. Workshops, short courses and seminars

In this section we focus on the training component of the proposed program. Specifically, in the next table, we outline the planned training elements for the 5 main identified skillsets. Note that a typical workshop is 3-4 hours long (net time) and will for the most part be conducted by an academic with an industry expert. A typical seminar is 1 hour to 1.5 hours long conducted by an industry expert. Short courses in this training program are generally 2 days long and can be conducted by both academics and industry experts.

B.1 Communications and Communications in International Environment

	Compulsory	**Optional**
Workshops	Communication strategy and structure	Electronic/multimedia communication
	Written communication	
	Graphical communication	Oral presentation and inter-personal communications
Seminars		Communication in international environment

B.2 Teamwork

	Compulsory	Optional
Workshops	Forming effective teams	Technical teaming
	Team operation	
Seminars	Collaboration practice in industry	

B.3 Risk and Change Management

	Compulsory	Optional
Seminars	Establish diverse connections and networks	
	Bringing intentional changes and advocacy	
Short Course		Risk mitigation and management

B.4 Knowledge and Vision of entrepreneurship and Enterprise

	Compulsory	Optional
Workshops	Enterprise culture, strategy, goals, and planning	Technical entrepreneurship
Seminars	Understanding the global societal, environmental and business context	Developing a global enterprise perspective
	Managing intellectual property and respecting legal process	Implementation and operations management
		Manufacturing supply chain operations

B.5 Integrated Knowledge and Methods in Aerospace Manufacturing Systems

	Compulsory	Optional
Workshops	Design implementation process	Hardware and software integration
	Hardware Manufacturing process	
	Software Implementing process	Emergence and interactions in systems
		Systems improvement and evolution
Seminars		Contemporary engineering issues and values
		Prioritization, focus, trade-offs, judgment and balance in product development
Short Courses	Design-of-experiments theories	Multi-objective Design (DFX)
		Sustainable design and manufacturing
		Information technologies in design, manufacturing and quality control
		Manufacturing optimization, simulation and modeling theories
		Polymer processing theories
	Design and manufacturing systems integration	Product quality control
		Composite materials
		Metal forming and joining process

C Industrial research internships and mentoring

The research will be conducted in the framework of CRIAQ projects, which requires the involvement of at least two companies and two universities. Moreover, students who have more than one supervisor will be preferred, all other things being equal. This will promote the possibility of students working in different laboratories, which will encourage the development of a holistic vision of manufacturing, as well as contribute to many of the CDIO attributes (disciplinary knowledge and reasoning, personal attributes (thinking, beliefs and values), relating to others (communication and collaboration), leading the innovation process). Even within the same University department, different research laboratories have different modus operandi. Trainees will learn to be flexible and will accumulate best practices from a variety of different perspectives.

If graduate students are to appreciate the many challenges associated with manufacturing real products, the mandatory industrial internships will be an invaluable tool in the education of a trainee. No matter how well constructed are the workshops and seminars that address industry-centric attributes, there is no substitution for the practice gained in a work term, no matter how brief. On the other hand, a work term comprising 20% of the trainee's time will normally not be enough to experience the full cycle of manufacturing. Therefore, the internship will have a structure in which the trainee will conduct a mini project, which will be based on the research topic, designed to take the trainee through the key industrial phases of manufacturing.

Moreover, the student will be assigned an industrial mentor with whom she/he will meet periodically to, not only, closely guide and evaluate the trainee during his internship period, but also establish a peer relation to address some emotional aspects the student may experience in his new industrial environment. This relation will enable to explore both: political savvy, personal skills and attitudes related to "Personal Inventory" (CDIO Syllabus 2.4.6), professional skills and attitudes in order to "Stay current in the World of Engineering" (CDIO Syllabus 2.5.4), and to create/grow student professional network. Such human interaction, outside of the working environment, will also be beneficial to address the emotional concern that HQP may experience passing, from a "safe" environment (university) where she/he is recognized to be among the best, to an "strange" environment (industry), where she/he receives feedback of missing competences rarely valued during her/his studies.

It should be noted that the training program will also encourage possibilities for international interactions and collaborations to enrich international cross-cultural skills.

Evaluation of Proposed Training Program

The performance of this training program will be continuously assessed by feedback from the industrial partners, industrial mentors, research supervisors and trained students. An Assessment Committee will make recommendations for changes. A closed-loop evaluation process based on existing CDIO approach shown in 4 has been established. It was decided to review the current training program after 2 years to make sure it meets possible shifts of industry requirements and expectations.

CONCLUDING REMARKS

The main objectives of the proposed training program are the following:

- Customize the CDIO concept to derive a methodology that is specific to the aerospace industry.
- Sensitize the professoriate to the needs of the aerospace industry regarding the attributes of graduate students and sensitize industry to the value added by hiring graduate students with advanced degrees and professional skills.

- Implement and evaluating a pilot program for educating 90 graduated trainees over the next 6 years.

The proposed training program will be successful if the students who complete it are equipped with scientific and technical knowledge as well as essential interpersonal, systems level, and product level skills to be able to integrate quickly into the aerospace manufacturing industrial workforce. They will understand the requirements of various streams of aerospace products, such as medium- to large-size airplane engine stream, helicopter engine stream, airplane systems and components design stream, manufacturing methods stream, etc. Equally importantly, they will be able to work together as part of an interdisciplinary team, be resourceful, be experienced at project planning and tracking, be aware of the standards of excellence and be able to assess their own work relative to those standards, be comfortable within a commercial manufacturing industry environment, be skilled communicators, and have a very good understanding of the complexity of product development in the aerospace industry. After taking this program, students will be job-ready (and thus highly desirable in the job market) and well placed to make a long-term contribution to Québec's aerospace industry.

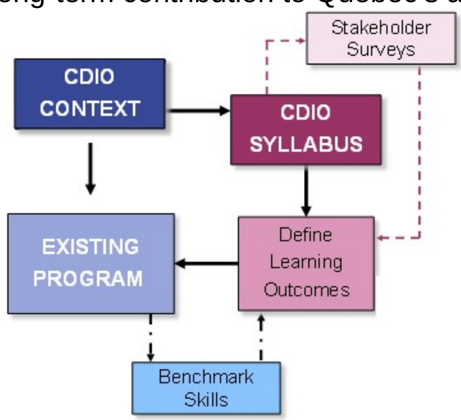

Figure 4: Evaluation process based on CDIO approach

REFERENCES

Edward F. Crawley, Kristina Edström & Tanya Stanko (2013), Educating Engineers for Research-Based Innovation – Creating the Learning Outcomes Framework, Proceedings of the 9th International CDIO Conference, MIT–Harvard, June 2013

Gouvernement du Québec (2014), http://www.economie.gouv.qc.ca/objectifs/informer/par-secteur-dactivite/aerospatiale/

BIOGRAPHICAL INFORMATION

Clément Fortin is Senior Advisor to the President of Skoltech University. Until April 2014, he was President and CEO of the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ). In September 2008, he was named Pratt & Whitney Canada Research Fellow. He is also fellow of the Canadian Society of Mechanical Engineering (CSME) and of the Engineering Institute of Canada. He acted as Co-chair for CDIO's North American Region from 2006 to 2010.

Jean-Paul Lemarquis is the Dean, Bombardier Engineering University of Bombardier Aerospace (third civil aircraft manufacturer in the world). He teaches integration project in the Aerospace Engineering Program at the École Polytechnique of Montreal. He deployed the CDIO approach in capstone projects for first year students of this program. His current professional activities focus on Technical Competences Development within engineering.

Stephen Yue, is a Professor and Chairman of the Department of Mining and Materials Engineering at McGill University and Director of the McGill Institute of Aerospace Engineering. His research area is in metallic materials, but in his bureaucratic roles, he is responsible for the pedagogical direction of both of the aforementioned units.

Yaoyao Fiona Zhao, is an Assistant Professor in the Department of Mechanical Engineering at McGill University, Montreal, Canada. Her current research focuses on design and manufacturing process modeling and optimization, additive manufacturing, sustainable manufacturing and manufacturing systems integration.

Michael Kokkolaras, is an Associate Professor of Mechanical Engineering at McGill University. His research interests lie in the broad areas of multidisciplinary optimization and simulation-based engineering design. He serves as Associate Editor of the ASME Journal of Mechanical Design, the CSME Transactions and the Optimization and Engineering Journal. He is executive member of the ASME Design Automation Executive Committee and Associate Fellow of the AIAA, serving on its Multidisciplinary Design Optimization Technical Committee.

Karen Packwood, is the director of special projects and is responsible for the Academy at CRIAQ. The CRIAQ Academy is mandated with the task of ensuring a new generation of aerospace entrepreneurs/innovators are well-prepared to integrate into companies upon graduation.

Corresponding author

Dr. Yaoyao Fiona Zhao
McGill University
817 Sherbrooke Street West
Montreal, Canada H3A 0C3
1-514-3982523
yaoyao.zhao@mcgill.ca

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Unported License.