Establishing a photonics teaching facility and programme in a Singapore secondary school

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ABSTRACT

As a premier school, Raffles Institution (RI) seeks relevant and forward-looking educational initiatives. Bringing emerging technologies into the school encourages the students to cultivate skills and attitudes that will empower them to ride the present and future waves of information and technology most meaningfully and innovatively. Photonics has diverse applications in the modern technological world, and Singapore aims to become a centre of excellence for optics and photonics in the region. However, a serious study of photonics begins only at the college level (K -11/12). Entrusted with Singapore's brightest young minds, RI pioneered the development of a Photonics Exploratory Laboratory (X-LAB), being the first among secondary (K-7 to K-10) schools in Singapore and possibly in the region. Young RI students are learning photonics fundamentals and recognizing photonics as a potentially rewarding field of study. With the expertise of lecturers from tertiary institutions, selected RI students are instructed in basic theory and trained in fundamental experiments. These students progress to embark on projects and in-depth studies under the wing of tertiary institutions and universities. Studies on Haidinger Fringes, Laser Doppler Anemometry and Optical Gratings have thus been successfully completed. Furthermore, the X-LAB acts as a focal point for students to experiment with Holography and Laser Animation.

Keywords: Education, curriculum broadening, gifted students, authentic learning, research, collaboration

1. INTRODUCTION

Raffles Institution (RI) was founded in 1823, and it is the oldest school in Singapore. It has achieved distinction through the process of history, spectacular achievements, a celebrated founder and illustrious old boys. Each year, it attracts the nation's brightest male students to partake of its special brand of education from K-7 to K-10. RI draws its strength from its tradition of excellence and innovation. At RI, apart from producing excellent academic results, we work in tandem with both academia and industry to create a multi-faceted realm of learning that will give our students the competitive edge in the knowledge-based economy of the 21st century.

1.1 Broadening the curriculum

The current exponential increase of knowledge brings to bear the interconnectedness among many disciplines. A real-world problem can probably best be examined from many perspectives for the most creative and efficient solution. In this light, we emphasize multi-disciplinary project work, deliver differentiated curricula for the academic subjects, place our students on mentorship programmes with expert academics and practitioners, and offer them a rich buffet of learning journeys, among other things.

1.2 Innovative education and cutting-edge technology

The school is committed to keeping both staff and students in phase with emerging ideas and technologies. Bringing promising nascent technologies into the school is a powerful means of sharpening the young minds in our midst. This way, we expose our students to fast growing areas of national economic importance. Singapore aims to become a vibrant and robust global hub of knowledge-driven industries, and RI aims to produce leaders, creators and innovators of this new age, both locally and internationally.

Seventh International Conference on Education and Training in Optics and Photonics,
Tuan-Kay Lim, Arthur H. Guenther, Editors, Proceedings of SPIE Vol. 4588 (2002)

In August 1999, Economic Development Board (EDB) managing director Liew Heng San announced Singapore's intention to be developed into an "optics hub", a centre of excellence for the optics and photonics industry in Asia. The immense market potential of photonics, coupled with the near-infinite possibilities it presents, was to be an important factor in the establishment of a photonics teaching facility in RI.

2. CHRONOLOGY OF EVENTS

2.1 The initial years at Ngee Ann Polytechnic

When the school approached the tertiary institutions for mentors who could provide tutelage for our students in authentic lab work, we received very generous responses, among them from Andrew Sabaratnam and his opto-electronics team at the Photonics Centre of Ngee Ann Polytechnic (NP). In 1998, a pioneering group of three students, accompanied by two RI physics teachers, Theresa Lai and Mark Wee, participated in a refreshing and rigorous photonics mentorship in NP quite unlike what is generally experienced in school.

The students received accelerated theoretical instruction not usually covered in the academic curriculum, and experienced real science with its associated challenges. For example, they needed to persevere in achieving that perfect alignment or perfect beam or perfect exposure. The mentors were patient but insisted on high standards. More than once, the students were chided for not treating the precision optics with adequate care!

Fig. 1: A Sabaratnam explaining the operation of a He-Ne laser.

The mentorship was enhanced by the relevance of photonics to real life, and the beauty and wonderment that photonics can create. At NP, the students went beyond learning 'hard-core' photonics to making their own holograms and viewing laser shows professionally synthesized in the NP Lab.

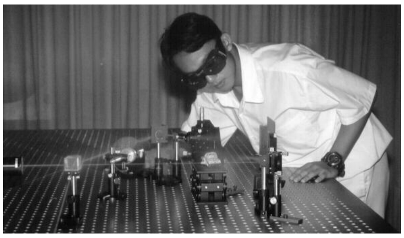

Fig. 2: Aligning the precision optics for producing a transmission hologram of a toy car.

Fig. 3: Transmission hologram of the toy car.

Fig. 4: Impressed by the beam effects from a laser animation system.

Probably more important than the mere acquisition of knowledge was the opportunity afforded to the students to nurture skills and attitudes critical in managing the current and future onslaught of information and technology synergistically. Through their interactions with the mentors, they were better able to understand the scientific way of thinking and doing things.

The encouraging start prompted the school to send a second group of three students in 1999 for a similar mentorship. Meanwhile the pioneering group brought their mentorship involvement to a new level through an application project – they investigated the parallelism of sample wedges through a study of Haidinger Fringes.

It was quite obvious that the photonics mentorship was benefiting the RI student. We had arrived at a sort of crossroads. How were we to progress from here?

Fig. 5: Pioneering RI students with their NP mentors. A Sabaratnam and H Gopal are seated second and third from right respectively. M Wee is seated second from left.

2.2 Photonics Exploratory Lab (X-LAB)
Periodic changes notwithstanding, the treatment of optics at the Singapore-Cambridge General Certificate of Education Ordinary Level (an education benchmark for 16- and 17-year olds) is relatively superficial. Students are examined on:

- General Wave Properties [Reflection and Refraction phenomena only]
- Reflection of Light
- Refraction of Light
- Converging Lenses
- Electromagnetic Spectrum

As a serious study of photonics commences much later, there is an inevitable talent drain of our brightest students. The RI student is frequently drawn to Law and Medicine. Given the increasing prominence and economic value of photonics, it seemed imperative that the young RI student be offered a sneak preview of this cutting-edge technology. It was clear that the NP photonics mentorship could only accommodate a tiny fraction of our students. In order to open this new window to a larger cross-section of our student population, we were emboldened to go forward and develop our own photonics teaching facility and programme.

2.2.1 Objectives
The concept of an on-site photonics lab, which we christened the Photonics Exploratory Lab (X-LAB), appealed for a variety of reasons:

- To expose more RI students to a fast growing area of national economic importance
- To provide a stimulating environment for nurturing research skills and launching the RI student into his personal research journey
- To provide intense and experiential programmes
- As a breeding ground for high-quality projects
- To demystify photonics

2.2.2 Designing and equipping
Based on the requirements of fundamental and prospective experiments, and cautious about the dangers of stray laser beams, we proceeded to lay the infrastructure for the X-LAB with invaluable advice from the NP mentors. Partitions were employed to compartmentalize concurrent photonics projects in mini-labs, while ordinary spaces were converted into a special holography lab and a processing lab.

The total available floor area for the X-LAB is approximately 110 sq. m.

The approximate floor areas for the various sections of the X-LAB are as follows:

- Main Lab 46 sq. m
  - Mini-lab 9 sq. m
- Holography Lab 23 sq. m
- Processing Lab 5 sq. m
- Laser Animation Lab 36 sq. m

In line with the crucial role of information technology in modern science, the X-LAB is equipped with desktop computers connected to the Internet, scanner and printer. In a sense, despite the finiteness of the numbers describing size, the X-LAB is a borderless centre of experimentation and learning.

In the matter of procuring precision photonics equipment, certain principles were adhered to:

- The versatility of equipment, whether employable in a variety of investigations
- The compatibility between the quality of equipment and level of experimentation
- Equipment cost and lifespan
- Beginning with the basics, and expanding as needs demand and with the benefit of hindsight
- Metric system and metric models
- Improvisation and adaptation of items

The inventory is nevertheless extraordinary for a secondary school laboratory:

- Helium-neon lasers
- High-speed silicon photodiode detectors
- High-speed digital oscilloscopes
- Spatial and neutral density filters
- Dichroic sheet polarisers
- Mirrors with dielectric coating and non-polarising beam-splitters
- Microscope objectives, lens kit, and target set consisting of slits, gratings, apertures
- Kinematic mounts and precision translators and stages
- Honeycomb breadboards
- Wavelength-specific safety goggles
- Holographic plates, chemical developers and holograms
- Laser show design software and projection system

Fig. 6: The main lab makes clever use of partitions to create isolated mini-labs.

Fig. 7: Each mini-lab is typically equipped with a laser, an oscilloscope, vibration-isolated breadboard, goggles, flashlights, lamps, screens and assorted hardware. The precision optics and detectors are kept in a humidifier cabinet when not in use.

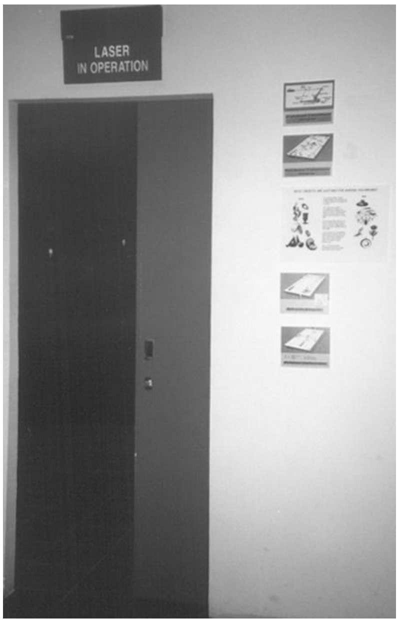

Fig. 8: Right inside the main lab – the entrance to the holography lab.

Fig. 9: Part of the holography lab. When not used for holography techniques, it has the capacity to host mini-labs.

Fig. 10: A small but fully-equipped processing lab. There is an exhaust blower for removing hazardous vapours.

Fig. 11: Students and teacher in the discussion room-cum-laser animation lab.

2.2.3 Our partners

Mindful of the rapidity of change in science and technology and the consequences of an insular approach, we sought to establish partnerships and networks with academia and industry.

We were privileged to gain the support of the following tertiary institution partners:

- Photonics Centre,
  Ngee Ann Polytechnic
- Department of Mechanical and Production Engineering, National University of Singapore (NUS)
- Photonics Research Group, Nanyang Technological University (NTU)
- School of Mechanical and Production Engineering, Nanyang Technological University (NTU)

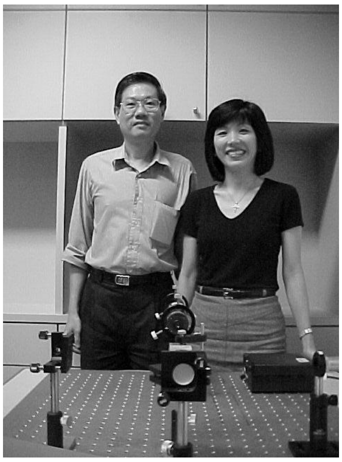

Fig. 12: H M Shang from the National University of Singapore with T Lai.

Fig. 13: Nadya Reinhand from the Russian Academy of Sciences paying a visit to the Photonics X-LAB while in Singapore to deliver a series of lectures.

From industry, we were excited to know that Agilent Technologies Singapore Pte Ltd shared our vision for the X-LAB. The generosity of Agilent in terms of an initial sponsorship of SGD$100,000 and a commitment to host internships speak of the belief in investing in the RI student. Our association with Agilent, and indeed with our partners in academia, is pivotal in ensuring that our educational efforts remain relevant to industry's changing needs.

Fig. 14: NP mentors with T Lai.

Fig. 15: Visitors from Agilent admiring the holograms made by RI students. Gene Endicott, Public Affairs Director responsible for worldwide community relations, is on the left.

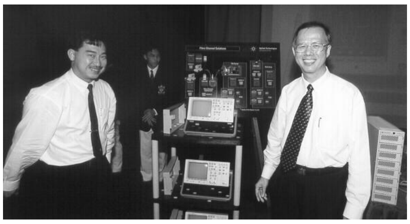

Fig. 16: Dato' Tan Bian Ee, President of Agilent Singapore, on the right, presenting a gift of digital oscilloscopes to the school.

Fig. 17: RI students interacting with an Agilent R&D engineer. Dato' Tan is on the left.

2.2.4 Official opening

The RI-Agilent Photonics X-LAB, together with the Life Sciences X-LAB, was officially launched on 22 April 2000 by Singapore's Minister for Education and Second Minister for Defence Rear Admiral Teo Chee Hean. The Minister reaffirmed RI's efforts in creating an incubator environment for nurturing future scientists.

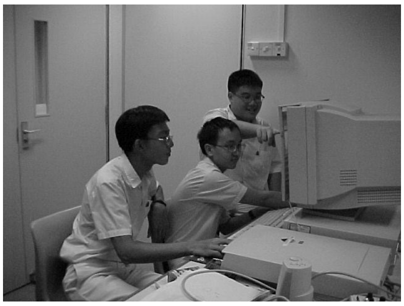

Fig. 18: The team of RI students tasked with creating the laser show for the official opening.

Fig. 19: Creating an eagle, an RI symbol.

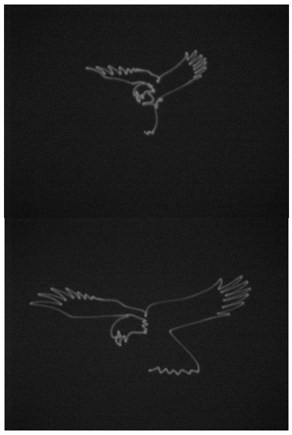

Fig. 20: Stages in the morphing of the eagle.

Fig. 21: The Minister unveils the plaque.

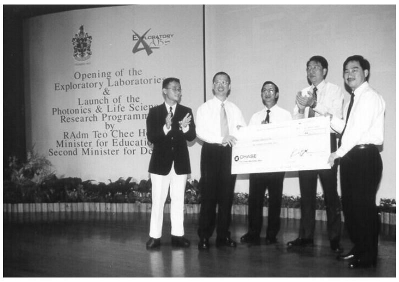

Fig. 22: The Minister presiding over the cheque presentation by Dato' Tan to the school.

Fig. 23: The Minister listening intently to a student's commentary.

3. PROGRAMMES

3.1 Photonics Introductory Module

This module is offered to Secondary 3 (K-9) students. It provides theoretical and practical instruction in photonics fundamentals. Depending on the progress of the students, the module lasts about 60 hours and spans half a year.

The theoretical component includes:

- Laser Safety
- Laser Basics
- Geometric Optics
- Polarisation
- Diffraction
- Interference and Interferometry
- Engineering R&D/applications
- Holography and applications

The practical component includes:

- Brewster's Angle
- Malus' Law
- Young's Double-Slits and Conditions for Interference
- Diffraction Gratings
- Michelson Interferometers
- Reflection Holography
- Real-Time Holographic Interferometry for Non-Destructive Testing

At the end of the module, the students write a report comprising:

- experimental data and interpretation
- set problems and solutions
- literature and web research

They also share their results and personal discoveries at the annual RI Mentorship Congress.

Fig. 24: Lecture session.

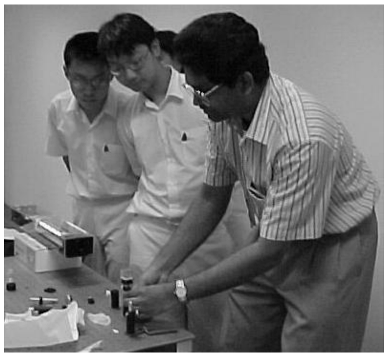

Fig. 25: First contact with lasers and precision optics.

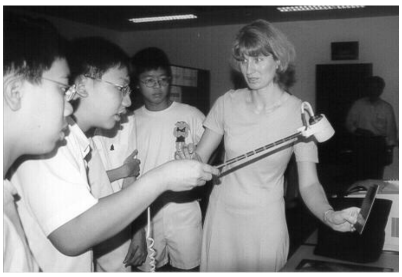

Fig. 26: The way holograms work.

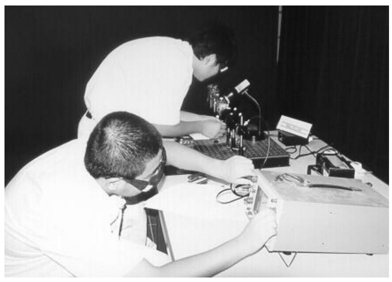

Fig. 27: Fully engaged in a mini-lab.

3.2 Photonics Research Module
This module is offered to promising Secondary 4 (K-10) students who have ‘graduated’ from the Introductory Module. Our partners propose projects and in-depth studies which are then matched with the students. With the fundamentals gleaned from the Introductory Module, the students are equipped to grasp the principles and techniques in engineering optics.

Some of the advanced studies include:

- Haidinger Fringes
- Laser Doppler Anemometry
- Optical Gratings for Measurement[1] and Surface Profiling[2]
- Microelectromechanical Systems
- Compound Semiconductor Epitaxial Layers
- Digital Holography

At the end of the module, the students write a report. The projects may also be further developed for participation in conferences and competitions.

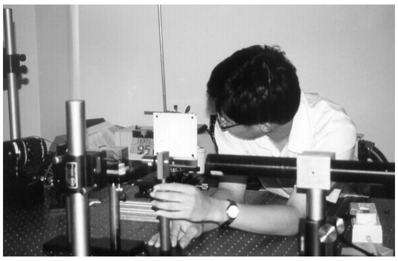

Fig. 28: Aligning the optics for obtaining a circular grating.

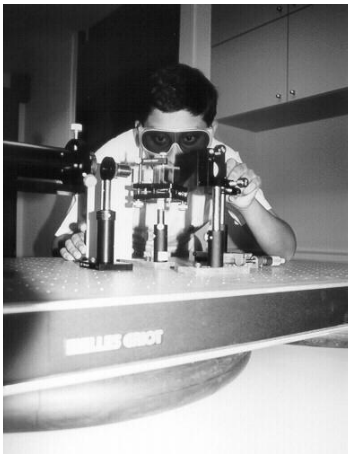

Fig. 29: Aligning the optics for obtaining a circular grating.

Fig. 30: A Merlion statuette is the object of investigation.

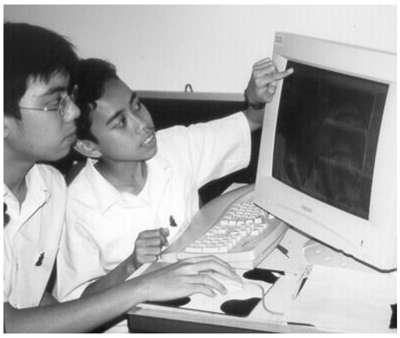

Fig. 31: Analysing the fringes projected on the statuette.

3.3 Holography Elective
This elective is offered to junior students as a form of enrichment and as an attractive preview to the promise of photonics.

The principle of holography is explained to these students in a comprehensible way. They learn the conditions, and actually go through the process of making a reflection hologram of their favourite objects from start to finish. It has proven to be an unforgettable experience for these students!

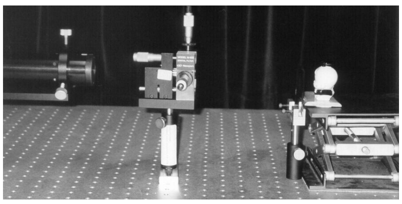

Fig. 32: Denisyuk’s method for obtaining a reflection hologram.

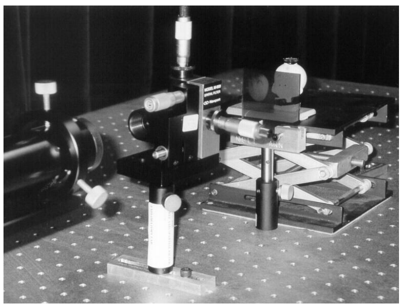

Fig. 33: Denisyuk’s method for obtaining a reflection hologram.

3.4 Laser Animation

The module and elective are offered to senior and junior students respectively.

Laser shows make use of lasers and precision components such as galvanometers and mirrors to enable the beams to dance to the whim and fancy of the show programmer. The generation of graphics frames synchronized with music is similar to what is produced in Walt Disney animation studios.

Laser animation holds appeal for many RI students because it is a fascinating combination of modern technology, art, music appreciation and story-telling, among other things. The students are introduced to the design software and aspects of film directing. Before long, they become proficient in creating, directing and editing a sequence of individual frames to the beat of music.

Our very own student-authored laser shows are becoming increasingly popular with the organizers of internal school events, not surprising since the shows are always well-received.

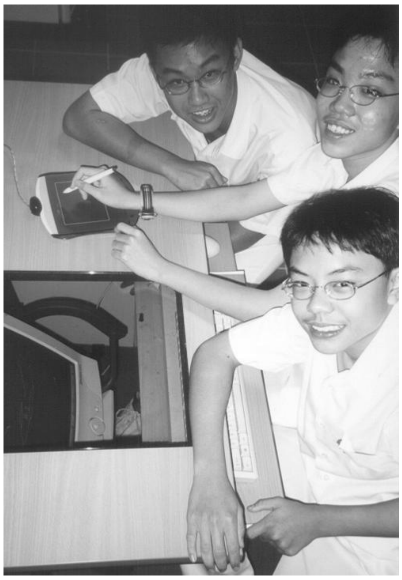

Fig. 34: A team of student laser show programmers taking a moment off from creating a frame.

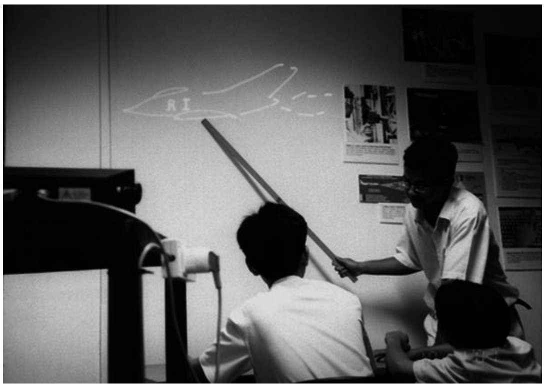

Fig. 35: A frame depicting a jet plane.

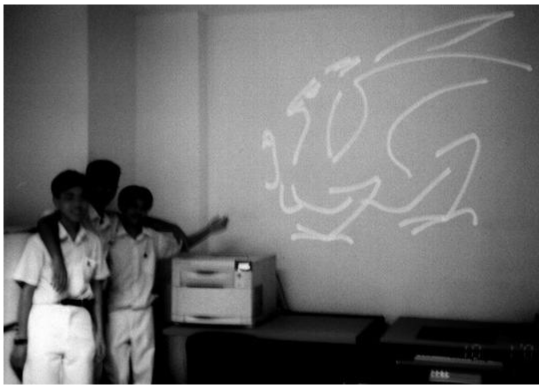

Fig. 36: A frame depicting a gryphon, another RI symbol.

3.5 RI Photonics Lectures

In March 2001, RI organized the inaugural RI Photonics Lectures to reach out to an even larger cross-section of our student population. As part of our philosophy of being in partnership with the community, teachers and students from other schools were invited to attend.

H M Shang from NUS engaged the audience with a demonstration of moiré patterns and an explanation of the use of similar patterns in industry.

R&D engineers from Agilent sustained the tempo with a talk on optical networking and a demonstration of communication transmission via fibre optics cable media.

The lectures were enlightening to the capacity audience. For the budding scientist and engineer, the occasion was most opportune.

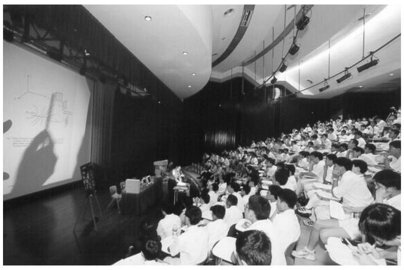

Fig. 37: An auditorium filled to capacity for the RI Photonics Lectures.

Fig. 38: A section of the captivated audience.

Fig. 39: Our guests from Agilent and NUS, the school executive committee, teachers and students, after the lectures.

4. LEARNING OUTCOMES

4.1 Tangibles

A pair of projects on optical gratings[1, 2] have been accepted for oral presentation at the 7th International Conference on Education and Training in Optics and Photonics 2001. This achievement represents a significant step in bringing the calibre of projects undertaken by the young RI student to a new level. The Photonics X-LAB has been a crucible of ideas, fostering close interaction between RI student and expert mentor. This melting pot has the potential to generate more instances of successful projects and a growing passion for photonics among young people. There are plans to adapt the student work being conducted in the X-LAB for other conferences and competitions, among them the National Science Talent Search (NSTS), Singapore Science & Engineering Fair (SSEF) and the Intel International Science & Engineering Fair (ISEF).

4.2 Intangibles

Many students who embarked on the Photonics Introductory Module did so with degrees of uncertainty and wonderment, but they gradually made sense of what they heard, saw and did. We are pleased to note that the uncertainty has been replaced by assurance now, and these students speak confidently about the subject with their mentors, teachers and peers. The X-LAB programmes have demystified photonics, and this is vital if the RI student is to be a leader, creator and innovator of knowledge in the new world.

Apart from the 'hard' knowledge acquired, the students further develop 'soft' skills and attitudes such as:

- Creative and critical thinking
- Seeking and evaluating information
- Troubleshooting
- Persevering
- Communicating ideas
- Leading and being a team player
- Lifelong learning

Fig. 40: The RI student as a potential leader, creator and innovator of the new economy.

5. CONCLUDING REMARKS

Almost two years since its conception, we have a more coherent picture of what the Photo nics X-LAB and its programmes should be like. We are in a state of dynamic flux, continually looking at how the X-LAB can be upgraded and how its programmes can be enhanced so that students benefit more greatly. At the root of it all is the desire to provide the best brand of education for the nation's brightest minds.

ACKNOWLEDGEMENTS

The X-LAB would not have materialized but for the amazing support and goodwill of our academic and industry partners. We also wish to thank the headmaster of Raffles Institution, Wong Siew Hoong, for the steadfast backing and belief.

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