Research Assessment Exercise 2020

Impact Case Study

University: The Hong Kong University of Science and Technology

Unit of Assessment (UoA): 7-Physics and Astronomy

Title of case study: Nurturing Future Scientists and Engineers Through Outreach Science Education

(1) Summary of the impact

Starting from 2002, the Department of Physics has collectively used its cutting-edge body of curiosity-driven and applied research on nanomaterials, metamaterials, condensed matter theory, and low-temperature physics to engage in extensive science education outreach work, leading to significant societal impact on secondary school physics education, STEM (science, technology engineering and math) education, and gifted education and science pedagogy in Hong Kong and the wider region. Specifically, HKUST physics research teams have used their breakthroughs to directly contribute to **a)** the establishment and on-going success of the Hong Kong Physics Olympiad (2003-) and Pan-Pearl River Delta Physics Olympiad, covering Hong Kong, Macau and mainland China (2005-), involving around 9,400 gifted students from 2013-19; **b)** provide content for training programs for Hong Kong secondary school students entering the International and Asian Physics Olympiads and a spin-off experimental physics kit based on their reflected electron diffraction research, which has been sold to schools and universities in Hong Kong and internationally, benefiting students and educators in science/STEM; **c)** deliver physics mini-lecture series, to 2,800 Hong Kong secondary students from 2013-19, inspiring young people to pursue physics higher education and careers.

(2) Underpinning research

In 2002-03, physicists at HKUST realized that secondary school students in some developed countries/regions showed a falling trend in science performance and interest, as reflected in the OECD's Programme for International Student Assessment (PISA), which posed a risk to students' future opportunities and ability to thrive in a world of rapid technological advancement. To mitigate this in Hong Kong, and to support Hong Kong government curriculum reforms in schools that emphasized lifelong and student-centered learning, including new policy on developing gifted and STEM education, they have since devoted collective effort to incorporate and deliver their research findings in outreach science education initiatives. Supported by educationists, the team based its work on the premise that the amazing nature of many physics discoveries can captivate both gifted and other school students, motivating them to pursue deeper understanding of science. Examples of their original research chosen for school outreach were selected for their interesting concepts and ability to be explained by faculty in ways that younger learners could understand. Those used to date include:

a) Gifted education competitions

i) *Sou et al* discovered a reflected high-energy electron diffraction phenomenon of a nanostructured zinc selenide surface **[Section 3, R1]**. Sou then designed an optical analogy of the phenomenon that can be performed by secondary students. It became one of two experimental problems in the 2016 Asian Physics Olympiad (APhO). From this, Sou developed an innovative experimental kit for school and university use, commercialized through a spin-off company.

ii) *Tam et al* developed a high-precision technique for measuring phase shifts when a light beam is reflected from the surface of metamaterials **[R2].** As an intriguing illustration of interference phenomena learned in secondary schools, it was used as an experimental problem in APhO 2016.

iii) *Law et al* proposed a model for recently discovered Ising superconductors. Their advance was a major contribution to the field due to its potential applications in quantum computers **[R3]**. Law paraphrased the advanced concepts using basic electromagnetic theory understandable by secondary school students. It was one of three problems set in the theoretical paper in APhO 2016.

iv) *Wen et al* discovered the giant electrorheological (GER) effect in suspension of nanoparticles. The yield strength breaks the theoretical upper bound based on the linear response assumption. The GER fluids can reversibly transform from a liquid to a solid within one-hundredth of a second and

hence are useful in microfluidic applications **[R4]**. The team used electrostatic dipole interactions understandable by secondary school students to explain the phenomenon and set an interesting question in the 2005 Pan-Pearl River Delta Physics Olympiad (PanPhO). Besides, the GER demonstration kit was a popular item in mini-lectures (Section b below).

v) *Jo et al* demonstrated all-optical implementation of spin-orbit coupling in ultracold atoms, and observed their symmetry-protected topological phases **[R5]**. The physics of ultracold atoms appeared as a question in the 2017 PanPhO.

b) Mini-lectures for secondary schools and general public outreach

i)*Wong et al* developed a policy for dynamic call admission control in wireless networks **[R6]**. Together with a computer game for demonstration, this became the core of mini-lectures and school talks on "Einstein and the atomic world", the algorithm being based on the theory of Brownian motion.

ii) *Sheng et al* discovered single-walled small-diameter carbon nanotubes embedded in a zeolite matrix exhibit superconducting behavior manifested as an anisotropic Meissner effect, with a superconducting gap and fluctuation supercurrent [**R7**], used in mini-lectures on nano-science.

iii) *Sou et al* developed a series of visible/solar-blind UV sensors, which was highlighted in the 2001 May issue of *Laser Focus World* in its "Newsbreaks" section **[R8]**. This became the content of mini-lectures on ultra-violet light and a (non-commercial) demonstration kit.

(3) References to the research

[R1] G. Wang, S. K. Lok, S. K. Chan, C. Wang, G. K. L. Wong, I. K. Sou, "The formation of an aligned 1D nanostructure on annealed Fe/ZnSe bilayers", Nanotechnology, 20, 215607 (4) (2009).

[R2] W. Gao, M. Xiao, C. T. Chan, and W. Y. Tam, "Determination of Zak phase by reflection phase in 1D photonic crystals", Optics Letters 40, 5259-5262 (2015).

[R3] J. M. Lu, O. Zeliuk, I. Leermakers, N. F. Q. Yuan, U. Zeitler, K. T. Law, and J. T. Ye, "Evidence for two-dimensional Ising superconductivity in gated MoS2", Science 350, 1353 (2015).

[R4] W. Wen, X. Huang, S. Yang, K. Lu, and P. Sheng, "The giant electrorheological effect in suspension of nanoparticles", Nature Materials 2, 727 (2003).

[R5] B. Song, L. Zhang, C. He, T. F. J. Poon, E. Hajiyev, S. Zhang, X.-J. Liu, and G.-B. Jo, "Observation of symmetry-protected topological band with ultracold fermions", Science Advances 4, eaao4748 (2018).

[R6] S. Wu, K. Y. M. Wong, and B. Li, "A dynamic call admission policy with precision QoS guarantee using stochastic control for mobile wireless networks", IEEE/ACM Trans. on Networking 10, 257-271 (2002);

[R7] Z. K. Tang, L. Zhang, N. Wang, X. X. Zhang, G. H. Wen, G. D. Li, J. N. Wang, C. T. Chan, and P. Sheng, "Superconductivity in 4 angstrom single-walled carbon nanotubes", Science, 292(5526):2462-5 (2001).

[R8] I. K. Sou, Marcus C. W. Wu, T. Sun, K. S. Wong, and G. K. L. Wong, "Molecular-beam-epitaxy-grown ZnMgS ultraviolet photodetectors", Appl. Phys. Lett. 78, 1811 (2001).

(4) Details of the impact

HKUST physicists have developed and used innovative platforms to share their research beyond the university realm, leading to impacts on *public policy implementation*, *student learning*, and *pedagogy* by instigating change in secondary school education through gifted, physics, and STEM (science, technology, engineering, math) education development; and *societal impact* via community outreach.

a) Public policy implementation through Olympiad training and organization: the Physics Department partnered with the HKSAR's Education Bureau (EDB) to deliver Physics Olympiad training and organization, which emerged as an important vehicle for developing gifted education. The Department has trained the Hong Kong team to compete in the International and Asian Physics Olympiads. In 2016, HKUST physicists organized the 17th APhO competition, with 193 student contestants from 26 countries/regions **[Section 5, S1]**. Problems based on their research were used [**Section 2, R1-R3**]. They have also organized the Hong Kong Olympiad contest and an annual Pan Pearl River Delta Physics Olympiad (PanPhO) since 2003 and 2005 respectively. Challenging questions based on HKUST physics research were set in PanPhO [e.g. **R4**]. Since 2013, about 9,400

students have participated in Hong Kong and Pan Pearl competitions. In 2010, the Center for the Development of the Gifted and Talented (CDGT) was founded at HKUST to offer gifted courses as an extension of the Olympiad training, with participation by over 100 Hong Kong schools so far [**S2**]. It worked closely with the government-sponsored Hong Kong Academy for Gifted Education, set up to implement gifted education. Chair Professor TK Ng, the Center's founder, went on to be the Academy's executive director (since 2014) and to mastermind the expansion of provision through the HK$800M Gifted Education Fund, approved by the Legislative Council [**S3**].

b) <u>Impact on pedagogy and student learning – experimental kit</u>: This impact was achieved through the kit that Sou developed for the 17th APhO competition. This was well received by leaders of the participating countries and more than 50 sets sold onsite. *Economic impact* has been achieved through New UV Technology Limited (NUVTL), founded by Sou and colleagues, which modified the kit for commercial sale to assist science/STEM education in secondary schools and universities. So far, about 40 kits have been sold/ordered locally and overseas.

The Olympiad activities and experimental kit were welcomed by EDB's Curriculum Development Institute (CDI) as contributions to developing Physics/STEM education, a policy priority **[S3, S4]**, as demonstrated by workshops co-organized by the CDI for secondary school teachers to develop pedagogical skills to adapt Olympiad questions and use the kit in classroom teaching, school-based assessment, and student projects **[S4]**. In testimony, O Kin Chit, Physics Panel Head and Assistant Principal, G.T. (Ellen Yeung) College "highly recommend(ed) it" for Hong Kong Diploma of Secondary Education teaching. "Our students can strengthen understanding of the concept of diffraction theory and nano-structures" **[S5]**, affirming the *impact on pedagogy and student learning.*

The Centre for Science and Engineering Promotion of University of Macau used the kit as a key component for onsite and mobile demonstrations to promote STEM education in primary and secondary schools. For example, the kit was used in 2018 for the "On the Go" project for secondary schools, with 500 students and teachers from seven schools participating via the University's STEM Car by March 2019 **[S6]**. Centre director Kam Weng Tam stated in testimony: "This kit allows students to learn and understand the novel fascinating reflected diffraction phenomena in both conceptual and quantitative ways… and get stimulated by its relevance to some real-life and natural phenomena." He wrote the kit was found to be "well suited as a compact and novel STEM teaching support in their schools". It had inspired him to collaborate with one school to develop games based on its physics concept. These were used in a recent training workshop for high school students and received very positive feedback **[S7]**. Meanwhile, Sou conducted a training workshop on the kit in the Center for secondary school principals, teachers, and students in February 2019. In evaluation, all 21 participants agreed it had "increased my knowledge of the novel diffraction phenomenon and its relevance in real life"; 90% were likely or very likely to use the knowledge gained in their teaching or learning; 81% agreed the kit was well suited for STEM education; and 91% indicated they were likely or very likely to recommend their school or university purchase it **[S8]**. The kit's STEM education value was relayed to wider audiences in media coverage **[S9]**.

c) <u>Impact on students and student learning – Olympiad training</u>: The Olympiads and training had great impact on participants and their life choices. Following the 17th APhO, three gold medalists subsequently entered HKUST. Students attested to how Olympiad activities changed their lives. Pok Man Tam, now a graduate student at University of Pennsylvania, writes that his involvement was where his "passionate journey in physics started and my career as a physicist germinated" [**S10**].

Sing Yin Secondary School physics teacher Shi Cheung is a past Hong Kong team bronze medalist in the 35th International Physics Olympiad, a Physics Olympiad trainer in two schools since 2009, and member of the HKPO Committee since 2010. He affirmed that HKUST's Physics Enhancement Program (PEP), which he attended in Secondary Six, had "a long-lasting impact on my life". He learnt new problem-solving skills and broadened his horizons "through the professors' descriptions of their researches". "Indeed, it was this year-long training that eventually changed my preference of undergraduate study from accountancy to physics." **[S11]** In assisting with the 2016 APhO, he saw how students responded to questions and experiments based on HKUST physicists' research [e.g. **R1**, **R2**, **R3**]: "Students who worked on these problems during the competition or came across them

during the PEP training in subsequent years could experience the thrill of encountering the frontiers of physics." This aroused their interest, motivating the pursuit of physics research **[S11]**.

In addition, the Olympiads stimulated secondary school teachers to train their students for the competition, broadening the education impact by influencing their pedagogy. Physics teacher Lit Hung Yung, also at Sing Yin Secondary School**,** wrote: "I have seen the impacts of such activities on my students and their growing enthusiasm and capabilities to be future physicists as well as found the link with the professors and their research benefiting me as a teacher." Nine of his students in the Olympiad program went on to study Physics at university, with five pursuing postgraduate study at leading US universities **[S12]**. "The training program has also made impact on my pedagogy in teaching physics." He shared knowledge on topics such as phase shift during reflection with his students and other teachers, and could better advise students on potential career paths from physics research **[S12]**. Kam Fung Yu, IT committee head, Our Lady of the Rosary College, testified to the importance of the program for maintaining physics standards in Hong Kong. After engagement with the physicists, he applied their ideas in class, with positive student feedback. "I reproduced the APhO 2016 experiment, the wave experiment with appropriate questioning students are able to think in more detail and have an additional perspective in understanding physics." **[S13]**

d) Impact on students and student learning – secondary school mini-lectures: Organized by the Department since 2002, with about 10 a year in Hong Kong and Pan-Pearl River Delta region schools. The content includes the Department's research [e.g. **R6-R8**]. So far about 100 mini-lectures have been delivered, with about 2,800 secondary students benefiting since 2013, and 18 repeat invitations in this period. HY Cheng, vice-principal, SKH Lam Woo Memorial Secondary School, wrote: "To help our students better understand STEM developments, we are looking for similar talks or demonstrations by your staff or undergraduate students" [**S14**]. Former Physics Research Assistant TK Lee, who arranged and gave mini-lectures from 2003-05, also stated in testimony how the experience and his physics research knowledge in wireless networks inspired him initially to take up a software engineering career and, since 2012, a move into Internet of Things products [**S15**].

e) Impact on society through Olympiad outreach to promote STEM education: The APhO competition was used in the Physics Department's other government-supported science outreach activities, including Hong Kong's Innovation and Technology Commission 2016 InnoCarnival, during which 1,700 participants engaged in Physics quizzes and 200 students attended a talk on cosmology, indicative of the interest kindled by their work. The team's participation in the 2017 and 2018 InnoCarnivals was equally well received.

(5) Sources to corroborate the impact

[**S1**] Asian Pacific Physics Newsletter vol. 5, 56-61 (2016)
[S2] CDGT website: http://www.cdgt.ust.hk/eng/index.php
[S3] Legislative Council Paper No. CB(4)1030/17-18(01), and letter of support from Dr Catherine K Chan, former Deputy Secretary, Education Bureau
[**S4**] Workshops co-organized by Curriculum Development Institute tcs.edb.gov.hk/tcs/admin/courses/previewCourse/forPortal.htm?courseId=CDI020161311&lang=en
[**S5**] Letter, O Kin Chit, Physics Panel Head, Assist. Principal, GT (Ellen Yeung) College
[S6] Comm. Office WeChat account (21.11.18), news item (12.03.19), Macau University
[**S7**] Letter, Prof Kam Weng Tam, Director, Centre for Science and Engineering Promotion, and Associate Dean, Faculty of Science and Technology, Macau University
[**S8**] Evaluation survey, training workshop for the experimental kit, Macau
[S9] Macau media articles on the experimental kit in STEM education
[S10] Letters, Pok Man Tam and Ho Tat Lam, IPhO and APhO medalists
[S11] Letter, Shi Cheung, Physics Teacher, Sing Yin Secondary School
[S12] Letter, Lit Hung Yung, Physics Teacher, Sing Yin Secondary School
[S13] Letter, Kam Fung Yu, Head of IT Committee, Our Lady of the Rosary College
[**S14**] Letter, HY Cheng, Vice Principal, SKH Lam Woo Memorial Secondary School
[S15] Letter, TK Lee, former Research Assistant, HKUST Physics Department