Institution: King's College London		
Unit of Assessment: 9 Physics		
Title of case study: Physics training aids sustainable development in African countries, Palestine and Afghanistan		
Period when the underpinning research was undertaken: 2011 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
(1) Bobby Acharya (2) John Ellis	(1) Professor of Theoretical Physics (2) Clerk Maxwell Chair of Theoretical Physics	(1) From 30/09/2011 (2) From 01/09/2010
Period when the claimed impact occurred: August 2013 - July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Most developing countries are underrepresented in physics education and research when compared to wealthier nations. Professor Bobby Acharya of King's College London (KCL) has made use of his body of research in high energy physics to build local capacity, address the gender gap in physics education and research, and improve the representation in physics for developing countries.

The African School of Fundamental Physics and Applications (ASP), established by Acharya and others, has trained over 300 qualified African physicists from approximately 30 different African countries (by the summer of 2018). Based on his research at KCL, Acharya has co-developed the curriculum of this graduate school, with support from Professor John Ellis and others. An evaluation report demonstrates that the ASP has contributed directly to keeping these physicists in the field and providing them with enhanced career opportunities. The ASP has also contributed to reducing the gender gap, both through training a large proportion (44%) of female students, and through being instrumental in the establishment of the Rwandan Association for Women in Science and Engineering (RAWISE) in 2016, which engages and inspires young women to study STEM subjects.

Acharya has also made significant contributions to physics curriculum development in Palestine and Afghanistan, substantially increasing Palestinian participation in CERN (also known as the European Laboratory for Particle Physics) and supporting the development of the technology sector in Afghanistan.

2. Underpinning research (indicative maximum 500 words)

Acharya is a leading researcher in a broad range of areas of high energy physics, particularly in string theory and particle physics. His standing in string theory is evidenced not only by his papers [R1-R3] but also by his participation in a prestigious Simons consortium award on Special Holonomy in Geometry, Analysis and Physics. In particle physics, this is demonstrated by the fact that he is a prominent member of the team of researchers working on the ATLAS experiment [R4] at the CERN Large Hadron Collider (LHC). Acharya is also a leading member of the Monopole and Exotics Detector (MoEDAL) collaboration [R5] at the LHC, which includes Ellis and several other KCL colleagues. There are very few researchers in the field of high energy physics worldwide with a spectrum of research outputs as broad as Acharya's.

In theoretical high energy physics, Acharya has led research in superstring theory and its application to physics beyond the Standard Model. In particular, Acharya has developed string theory models of particle physics that give rise to novel dark matter particles [R1] and have other applications in cosmology. He has classified dark matter candidates in this context and has expertise in hadron collider particle phenomenology, concerning long-lived particles [R5], the top quark and the Higgs boson [R4], as well as searches for physics beyond the Standard Model.

Ellis is a world expert who researches on the Standard Model, the Higgs boson, models for physics beyond the Standard Model [R6] and their implications for cosmology.

3. References to the research (indicative maximum of six references)

[R1] **Acharya, B. S.**, Ellis, S. A. R., Kane, G. L., Nelson, B. D., & Perry, M. (2018). Categorisation and detection of dark matter candidates from string/M-theory hidden sectors. *Journal of High Energy Physics,* 2018(9), [130]. DOI: 10.1007/JHEP09(2018)130

[R2] **Acharya, B. S.**, Kane, G., & Kumar, P. (2012). Compactified string theories – generic predictions for particle physics. *International Journal of Modern Physics A,* 27(12), [1230012]. DOI: 10.1142/S0217751X12300128

[R3] **Acharya, B. S.**, Maharana, A., & Muia, F. (2019). Hidden sectors in string theory: kinetic mixing, fifth forces and quintessence. *Journal of High Energy Physics*, 2019(3), [48]. DOI: 10.1007/JHEP03(2019)048

[R4] Aaboud, M., […], **Acharya, B. S.**, & Collaborators, ATLAS. (2018). Observation of Higgs boson production in association with a top quark pair at the LHC with the ATLAS detector. *Physics. Letters. B,* 784, 173-191. DOI: 10.1016/j.physletb.2018.07.035

[R5] **Acharya, B. S.**, De Roeck, A., **Ellis J.**, Ghosh, D. K., Masełek, R., Panizzo, G., Pinfold, J. L., Sakurai, K., Shaa, A., & Wall, A. (2020). Prospects of searches for long lived particles with MoEDAL. *The European Physical Journal C*, 80(6), [572]. DOI: 10.1140/epjc/s10052-020-8093-5

[R6] **Ellis, J.**, Murphy, C. W., Sanz, V., & You, T. (2018) Updated global SMEFT fit to Higgs, diboson and electroweak data. *Journal of High Energy Physics*, 2018(6), [146]. DOI: 10.1007/JHEP06(2018)146

Simons Collaboration Grant on Special Holonomy in Geometry, Analysis and Physics, USD14M grant, 2016-2023

4. Details of the impact (indicative maximum 750 words)

Acharya's knowledge acquired as a forefront researcher at KCL with a unique range of expertise in many areas of high energy physics, extending from string theory to theoretical and experimental particle physics (as outlined in section 2 and 3), has been essential for the development and success of educational and training programmes in Palestine, Afghanistan, and all over Africa, which Acharya has initiated, designed, and developed. Acharya's work in Africa and Palestine has been supported by his colleague Ellis.

In developing countries, which are generally lagging in science, technology, and education compared to developed countries, increased representation can lead to significant advancements in fundamental research. This can help bridge the gap between scientific research and economic development in these countries. Moreover, gender equality, a fundamental human right and global priority, is usually lacking in the field of academia, and this is especially pronounced in the context of developing countries.

To this end, the activities developed by Acharya have led to increased representation in areas of physics across these countries. Acharya's work has been particularly impactful in bringing gender parity and increased representation in the field of tertiary education, specifically in sub-Saharan Africa. In 2018, through the award of the prestigious Lawrence Bragg Gold Medal and Prize by the Institute of Physics, Acharya was internationally recognised for his *"contributions as the driver of several projects to teach and promote physics in the developing world, with the ultimate aim of developing sustainable physics research in those countries".* [S1, p.15]

African School of Fundamental Physics and Applications (ASP)

In 2008, Acharya and Ellis co-created the African School of Fundamental Physics and Applications (ASP) [S2]. Since then, Acharya has taken a leading role in its co-ordination and continuing development [S3]. The ASP is a 3-week graduate physics summer school held biennially in an African country and aims to promote, foster, and teach fundamental physics topics and applications to the brightest young physicists in Africa. Its goal is to address the problem of underrepresentation of Africans in the field of particle physics, and also to build capacity through outreach to local schools. KCL is one of the acknowledged sponsors of ASP.

Over the years, Acharya has designed and developed the curriculum of the ASP, which was established *"to build capacity to harvest and interpret the results of current and future physics*

experiments with particle accelerators" [S4], based on the breadth of his research knowledge and his body of work. The areas of Acharya's and Ellis' research (outlined in sections 2 and 3) have been major topics of lectures at ASP, notably those given by Acharya and Ellis themselves in which they have also highlighted their latest research findings. In addition to lectures, Acharya's unique knowledge, perspective and range of contacts has enabled him to lead the strategy of ASP, gather resources for it, and shape the scientific programme, bringing in other lecturers with world leading research knowledge (including others from KCL such as Jean Alexandre). Ellis, who along with Acharya is a member of ASP's International Organising Committee, has supported Acharya in his role in developing and leading the ASP.

For most of the students, attending the ASP is the first time that they meet similar young African physicists from other parts of Africa. They also gain access to physicists from around the globe who are invited to give lectures. Students also participate in outreach activities in the local community where the school takes place. These usually include physics masterclasses for local high school teachers and their students. Summary information about the school's past student demographics and statistics is as follows [S3, p.4]:

Year	Country	Student Demographics
2012	Ghana	50 students from 14 African Countries. 22% female
2014	Senegal	56 students from 21 African Countries. 32% female
2016	Rwanda	75 students from 29 African Countries. 39% female
2018	Namibia	85 students from 26 African Countries. 41% female
2020*	Morocco	85 students from 24 African Countries. 44% female

**Postponed to 2021 due to COVID-19 pandemic.*

Diversity in terms of representation from different countries in Africa has steadily increased, as has female participation. Globally, there are very few advanced graduate schools in physics and mathematics that have more than 30% female students.

Enhancing skills and careers of African physicists through ASP: A survey of former ASP students was carried out in 2020 [S3]. The survey solicited quantitative feedback data and qualitative testimonial responses from the former students. Students testified that they had used the knowledge and experiences from ASP schools to gain employment in, for example, technology companies; to deploy effective teaching methods when they had subsequently gone on to teach; and to boost career opportunities in the field of physics. 89% of respondents were studying or working in the education sector, with more than 50% having moved on to a different institution.

> "*Through this school I was able to go to Paris for a new Master's program."*
>
> *"I was able to get full funding for my Master's program at the African University of Science and Technology, Abuja, Nigeria, a three-month internship at Brookhaven National Laboratory, and, a one-year internship at the Nigerian Nuclear Regulatory Authority."*
>
> *"My presentation skills improved as did my ability to conceive and institute research projects."*
> - Former ASP students [S3]

Many respondents testified that ASP provided knowledge, information, and/or networking opportunities that directly led to them obtaining new positions in universities or other STEM-related positions in both Africa and other countries outside of Africa. This includes eight PhD students, four MSc students, nine lecturers, and two postdocs. Some reported working in tech companies, including one as a data scientist and another as an AI resident at Google Brain. Therefore, the survey demonstrated a clear positive development of skills, knowledge, and career confidence from having attended an ASP school.

Improving physics teaching through ASP: The ASP has encouraged many of its students into teaching and lecturing roles, and has empowered them with improved teaching skills. Many respondees in the ASP report [S3] state that the ASP experience has directly influenced them in their teaching work. These teaching activities include: teaching mathematics and physics to undergraduate

students, teaching mathematics and physics at high schools, particularly to underprivileged students, and providing private tuition.

> "*At the University level, I taught first year science students who study general physics. I took them through tutorial questions and thereafter graded their assignments. I was also involved in laboratory demonstrations during practical classes for the students. Each class has about 150 students. The students are of chemistry, medicine, surgery, agricultural sciences, microbiology, and pharmacy. At the high school level, I took part in volunteering work to teach students mathematics and information technology. These are students who could not afford expensive private schools and do not have adequate access to science teachers. Each class is about 65 strong and I was involved with four classes*." - Former ASP student [S3, p.36]

Improving representation through ASP - BAME physicists and gender parity: The ASP have, to date, trained over 300 qualified African physicists from over 30 different African countries. The survey and figures above demonstrate that ASP has contributed directly to keeping these physicists in the field by providing knowledge, training and careers advice/support. It is well understood that black physicists are underrepresented at senior levels globally: for example, there are no black theoretical high energy physics professors in the UK. The ASP plays a leading role in addressing African representation in physics.

In addition, the outreach activities of ASP students encourage school students and undergraduates to pursue scientific study and careers.

> *"[Since attending ASP] I do mentorships for high school and undergraduate students in Kenya. Through these mentorships I help them realize that science is not hard and that anybody can do it. I have accessed around 5,000 students and 11 high schools. I have helped 10 girls get scholarship for their masters and 53 students access high school education.*" - Former ASP student [S3, p.30]

The ASP schools have also directly contributed to closing the gender gap in STEM subjects in sub-Saharan Africa by maintaining a high gender ratio at the schools. At approximately 40% in the last two schools (2016 and 2018), the proportion of female participants is higher than the ratio in comparable graduate schools in Europe or the US. This is particularly significant in that nations in sub-Saharan Africa exhibit some of the worst rates of gender parity in STEM subjects in the world [S5].

A testimonial from the Rwandan Government (Ministry of Education) asserts that ASP (specifically mentioning Acharya and Ellis) played a significant role in 2016 in the development of RAWISE, the Rwandan Association for Women in Science and Engineering. This association actively engages and inspires young women to study STEM subjects via a range of activities.

> "*During ASP2016 young Rwandan women physicists came together, with support of Dr Marie Christine Gasingirwa, the then Director General Science Technology and Research in the Ministry of Education. ASP 2016 inspired them to initiate a forum that later resulted in the creation of the Rwandan Association for Women in Science and Engineering (RAWISE)*" [S6]

RAWISE organises a range of activities, including boot camps aimed at secondary school girls preparing to choose their A-level subjects, talks and visits aimed at schoolgirls, seminars for teachers, practical lab sessions, science competitions in schools, celebration of science events and prize-giving events.

> *"Through such engagement girls are overcoming their lack of confidence this has boosted their competencies, interests, ambitions to an extent that they have started outperforming boys in STEM subjects in school national examinations!"* [S6]

Impact on Physics Curriculum in Palestine

For over a decade, Acharya has been working with young Palestinian physics students. This began with him supervising and then collaborating with a Palestinian PhD student on the ATLAS experiment in CERN. From 2013, he designed and taught a course in particle physics at Birzeit University as part of their Master's programme in physics. In support of Acharya, Ellis has also shared his research in lectures in Palestine.

The particle physics course at Birzeit University was born during research discussions (on the topic of top quark physics at hadron colliders) between Acharya and the Former Head of Department of Physics' department at Birzeit University. The course itself delivered up-to-date methods and results to the students surrounding the (then) newly discovered Higgs boson, which Acharya was an expert on and which "*inspired many of the Palestinian physicists who took the course over the years"*. It also included aspects of physics beyond the Standard Model, another area of expertise of Acharya, and has led to him supervising the PhD of Marwan Najjar at KCL in this field. [S7]

> "*It is extremely clear that without Acharya's research expertise and accomplishments at that time that the course in Birzeit would not have happened*." [S7]

To date, approximately 50 Palestinian physicists have taken Acharya's course at Birzeit University, many of whom followed on to continue to work in the field of high energy physics. Birzeit University credits Acharya's course with capacity building and development of Palestinian physicists, and in particular with having a very positive impact in increasing the representation of Palestinians in the field of high energy physics [S7], noting that most of the CERN users from Palestine took this course (in 2013 there were no Palestinian users at CERN: by 2020 there were 7) [S8].

Impact on curriculum development in Afghanistan

Since 2018, Acharya has worked with faculty members from Kabul University to improve the teaching quality and create a nurturing research environment. This has included supervising Master's research on the ATLAS experiment and designing the physics curriculum at the university. Before this programme was initiated, there were only two physicists working in Kabul with current training in modern particle physics. Acharya's work has led to increased applications to the physics course, and his support has led to improved quality of physics graduates, a necessity to support the fledgling technology sector in Afghanistan. The programme also produced five scholarships with the IASBS institute in Iran for the Master's programme in 2019. [S9]

> "*Because of this opportunity, students are now passionate in the undergraduate program at universities in Afghanistan to learn physics and have an excellent transcript to be able to benefit from these scholarships… [The programme] allowed two faculty members (Baktash Amini and Ahmad Sajad Nazari) at Kabul University to conduct their master's thesis research on the top quark physics using the ATLAS experiment at CERN Large Hadron Collider under your supervision which will undoubtedly enhance their knowledge and ultimately help them gain excellent teaching skills, which added with the development of the new curriculum with your cooperation will be a ground-breaking achievement for Kabul University*." [S9]

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Institute of Physics – Annual report 2018 (Awards list on p.15)

[S2] ASP website

[S3] ASP Evaluation report

[S4] ASP 2012 webpage

[S5] World Economic Forum - Women in STEM (2020)

[S6] Testimonial from Rwandan Ministry of Education

[S7] Testimonial from Former Head of Department of Physics department (and Director of the Master Program in Physics) at Birzeit University (Palestine)

[S8] CERN user data: 2012; 2020

[S9] Testimonial from Physics Faculty at Kabul University (Afghanistan)