



Lighting the path: empowering girls through optics outreach in Pakistan

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In memory of Professor Gallieno Denardo, ICTP Italy

This write-up presents the outreach journey of the Active Learning in Optics (ALO) group at the Department of Physics, Quaid-i-Azam University (QAU), Islamabad. Founded in 2016, ALO's mission is to promote science education—particularly optics and photonics—among underrepresented female students in Pakistan. The inspiration for this initiative was drawn from UNESCO's International Year of Light (2015) and from the mentorship and vision of Professor Gallieno Denardo, whose dedication to science outreach and education at ICTP continues to inspire generations. Over the past years, ALO has conducted more than 90 outreach sessions in schools and women's universities across Pakistan. This write-up describes the pedagogical approach, regional outreach strategies, challenges, and achievements of ALO, highlighting its contribution to empowering young women through science in Pakistan.

1 Active Learning in Optics (ALO)

Gender gap in Pakistan: Challenges and Opportunities

Pakistan, a developing nation striving to accelerate economic growth and align with rapidly advancing regional economies, recognizes education as a cornerstone of national development. Among its central priorities is promoting gender equality, particularly in access to education. Despite policy reforms and international commitments—including the UNESCO Sustainable Development Goals (SDGs)—significant gaps persist. SDG 4 seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, with the UNESCO Institute for Statistics (UIS) monitoring progress through data collection and reporting [1]. Likewise, SDG 5 emphasizes achieving gender equality and empowering all women and girls. While UNESCO is not the sole custodian of this goal, it supports gender-responsive educational policies and ensures girls and women have equal opportunities to learn, participate, and thrive [2].

Women and girls in Pakistan face structural barriers rooted in socio-cultural norms, economic constraints, and geographic disparities. In many households—especially in rural and low-income communities—girls are expected to manage domestic responsibilities, and decisions regarding their education are often made by male guardians. Early marriage further restricts their educational opportunities, despite cultural and religious teachings that emphasize learning for both genders.

Statistical evidence underscores this inequity. According to the Girls' Education in Pakistan: Trends & Statistics 2022–23 report, approximately 21 million girls are enrolled in educational institutions compared with 25 million boys, while an estimated 13.7 million girls remain out of school [3]. The out-of-school rate for girls from primary to higher-secondary levels stands at 41.5%, compared with 34.9% for boys [4]. Literacy indicators reveal similar gender gaps: the national literacy rate is around 62–63%, with male

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literacy at 73% and female literacy at 51–52% [5]. Urban areas perform significantly better (74.1%) than rural regions (51.6%) [6]. Provincial differences are also stark—female literacy in Punjab is 60.2%, while in Balochistan it drops to 32.8%.

Provincial school enrollment data show the same uneven landscape: nearly 38% of children aged 5–16 remain unenrolled, with girls disproportionately affected [7]. Balochistan has the highest out-of-school rate at 69%, followed by Sindh at 47%, while Punjab and Khyber Pakhtunkhwa (KP) perform somewhat better at 30–32%. Yet even these rates represent millions of excluded learners—most of them girls. Poverty remains a defining factor: families often prioritize boys' education due to perceived higher economic returns, while girls' schooling is seen as secondary or optional [8].

These disparities highlight the urgent need to strengthen educational opportunities for girls, especially in STEM fields. Limited access to practical science, a shortage of trained female role models, and persistent stereotypes continue to discourage young women from pursuing studies in physics, engineering, and technology-driven careers [9].

Within this global and national context, the educational vision of Prof Denardo, who devoted his career at the Abdus Salam International Centre for Theoretical Physics (ICTP) to advancing optics education and empowering scientists from developing countries—offers both inspiration and direction [10]. His emphasis on inclusivity, mentorship, and hands-on learning directly resonates with the philosophy underpinning the Active Learning in Optics (ALO) program. The present work, in many ways, extends his legacy by fostering scientific curiosity and confidence among young women in Pakistan through optics-based outreach.

Making science tangible: Why Optics?

Building on the educational philosophy championed by Prof Denardo—who believed that Science becomes meaningful only when it is experienced rather than memorized—the Active Learning in Optics (ALO) initiative embodies this principle within the context of Pakistan's educational landscape.

Access to quality science education in Pakistan remains uneven, especially in rural and underserved regions where schools often lack laboratory facilities, trained educators, and hands-on learning materials. Science instruction is largely theoretical, leaving students detached from real-world connections. As a result, many perceive science as abstract and difficult.

Optics, however, offers a uniquely tangible approach. Students can directly observe and interact with phenomena such as reflection, refraction, diffraction, and polarization. Hands-on experiments with lenses, mirrors, and lasers help learners bridge the gap between theory and experience, sparking curiosity, creativity, and critical thinking.

Outreach initiatives like ALO bring these interactive opportunities directly to students, including those in remote and marginalized communities. By demonstrating real-life applications—ranging from fiber-optic communication to medical imaging—ALO stimulates interest in STEM careers and helps counter gender disparities in physics and engineering.

Support from partners such as the SPIE Outreach Grant has enabled ALO to expand its geographical reach, improve its resource capacity, and sustain long-term engagement. Within this broader framework, ALO demonstrates how targeted, experiential science programs can bridge educational inequalities and inspire the next generation of scientists and innovators in Pakistan.

2 My (IA) journey in optics and my Mentor, Prof Galliano Denardo- A vision of one of the authors

The Active Learning in Optics initiative was not conceived in isolation—it is the culmination of decades of personal experience, mentorship, and inspiration drawn from remarkable educators and scientists.

Among them, the late Prof Denardo of the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, holds a special place in my life and professional journey.

As I (IA) write this article for the Special Edition of the *Asian Journal of Physics* dedicated to Prof Denardo, memories take me back to 1988—my first visit to ICTP to attend the Winter College on Lasers Physics: Semiconductor Lasers and integrated Optics, held at the Adriatico Lecture Hall from February 22 to March 11, 1988. It was during this visit that I had the honor of meeting Prof Abdus Salam and Prof Denardo—two individuals who profoundly shaped my path in science.

I (IA) completed both my M S and Ph D in Physics at Quaid-i-Azam University (QAU), Islamabad, Pakistan, where Prof Salam's legacy was deeply rooted in our department's research culture. During the final semester of our master's program, a newly joined faculty member, Prof M Suhail Zubairy, offered a course titled Quantum Electronics. This subject opened an entirely new horizon for us. When we later enrolled in the M Phil-leading-to-Ph D program, I (IA) chose Quantum Optics as my specialization, while MZ selected Classical Optics—an academic decision that defined the rest of our career.

My selection for the Winter College on Lasers at ICTP was both thrilling and challenging. At that time, it was rare for an unmarried woman from South Asia to travel abroad alone, but my maternal grandfather supported me wholeheartedly. That journey—my first international trip—proved transformative. Meeting Prof Salam and engaging with global experts in laser physics broadened my worldview. Prof Denardo, serving as the local course director, stood out immediately for his warmth, energy, and deep humanity.



Photo 1. Winter College on Lasers Physics: Semiconductor Lasers and integrated Optics 1988: (ICTP Photo Archives/Massimo Silvano.)

I (IA) got married to my senior colleague, Mr M Zahid, in 1989, shortly after completing my Ph D in record time.

We shared the same supervisor, Prof Muhammad Sohail Zubairy, and worked in closely related research areas. I (IA) worked on the topic "Quantum Theory of Two-photon micro-maser", publishing a

number of papers [11-16], while his (MZ) Ph D on, “A Study of the Coherence Properties of Partially Coherent Beams,” examining the second-order coherence of generalized Schell-model sources [17], the directionality of partially coherent Bessel–Gauss beams [18], and the coherence characteristics of second-harmonic beams generated by a partially coherent pump [19].

With our overlapping research interests, we naturally began attending the ICTP Winter Colleges on Optics together. Over the years, we had the privilege of meeting Prof Denardo on many occasions during ICTP programs, including the Third Training College on Physics and Technology of Lasers and Optical Fibre (1992), the Second Winter College on Optics (1995), and later the Winter College on Optics and Photonics (2000). In the summer of 2005, I (IA) made my regular Associate visit to ICTP.

From 2000 onward, ICTP became a recurring home of learning and inspiration for me—one where I returned in many roles over the years: student, associate, TRIL fellow, tutor, and eventually lecturer. A defining moment came during the closing ceremony of the 2000 Winter College, when participants from developing countries expressed difficulty in following advanced lectures. I (IA) proposed that faculty members like me could assist others by explaining key concepts informally in the evenings. These informal teaching sessions became the seed of what would later grow into my passion for optics outreach.

That experience helped me realize that while research strengthens one as a scientist, teaching transforms communities. Prof Denardo’s trust in my teaching ability and his constant encouragement inspired me to devote my efforts to those who needed them most—young women in Pakistan’s underserved regions.

During this period, my (IA) research also expanded into quantum optics, including our study “The Role of Pump Phase Fluctuations in a Micro-maser” [16]. In this work, we investigated how pump phase fluctuations influence steady-state squeezing in a one-photon micro-maser for both high- and finite-Q cavities. By preparing the gain medium in a partially coherent superposition—reflecting the finite linewidth of the pump—we showed that substantial squeezing persists even in the presence of phase noise: approximately 40% in high-Q and 25% in finite-Q cavities, compared to about 55% in the ideal, fluctuation-free case. These results aligned with earlier theoretical predictions and contributed to a deeper understanding of coherence phenomena in cavity quantum electrodynamics.

Building on this body of work, IA was nominated in 2004 for what was then the ICO/ICTP Award [20], later renamed the ICO/ICTP Galliano Denardo Award, which IA shared with Prof Revati Kulkarni from India. In 2007, IA began teaching at the Preparatory School to the Winter College on Optics, designed to strengthen participants’ foundations in optics and lasers. Along with Prof Anna Consortini and Prof Miguel Alonso, I served as a tutor, helping students build confidence before the advanced lectures began. IA had first met Prof Consortini during the Second Winter College on Optics in 1995, but from 2007 onward IA was fortunate to spend meaningful time with her and learn from her. IA consider her one of my mentors [21]. Sadly, Prof Denardo passed away unexpectedly in 2007 while we were planning the next Preparatory School. His passing was a great loss, both personally and to the ICTP community. Yet his spirit continues through the programs he nurtured and the people he inspired. Under the supportive leadership of Prof Joseph Niemela, IA continued teaching at ICTP and was encouraged to expand my outreach activities for young female students in Pakistan.

It was from those early teaching sessions at ICTP that Active Learning in Optics (ALO) eventually emerged. Prof Denardo’s confidence, compassion, and belief in education’s power to uplift communities continue to guide every outreach session we conduct. We dedicate all my optics outreach efforts to his memory—with gratitude and admiration for a mentor whose light continues to illuminate my (Imrana) path.

Educational Philosophy

ALO employs an inquiry-based, experiential learning approach that prioritizes active exploration over rote memorization. Demonstrations are intentionally designed to be low-cost and accessible, combining

everyday materials with professional-grade optical kits provided by organizations such as Thorlabs, Optica, and SPIE.

Outreach design and implementation

Each outreach event includes following three integrated components:

1. Concept Introduction – An interactive overview of the fundamentals of light and optics.
2. Hands-on Experiments – Small-group engagement with optical phenomena including reflection, refraction, diffraction, interference, and polarization.
3. Motivation and Career Guidance – Discussions encouraging girls to pursue higher education and STEM careers.



Photo 2. (a) ICO/ICTP 2004 award winners Imrana Ashraf with ICO president René Dandliker, (b) Prof G Denardo with Imrana Ashraf: ICTP Photo Archives/Ludovico Scrobogna

Sessions are coordinated with local faculty to ensure curriculum alignment and sustained academic follow-up.

Outreach footprint: From twin cities to the mountains

ALO's core objectives are to enhance STEM education, promote scientific literacy, and cultivate problem-solving and critical-thinking skills among students [22-28]. Initially self-funded, ALO gradually expanded its geographical reach in 2019 and further strengthened this growth after receiving SPIE Outreach Grants in 2023 and 2024 [29,30]. These grants enabled the team to extend activities into remote districts of Pakistan—broadening access to underserved communities and inspiring students who had limited exposure to science.

Overcoming barriers in optics outreach

The ALO team is committed to fostering curiosity and scientific thinking among underrepresented communities—particularly in Pakistan’s northern regions and women’s universities—through engaging lectures, hands-on experiments, and interactive workshops.

Despite their enthusiasm and perseverance, the team continues to face several on-the-ground challenges, including:

- Managing large audiences, often comprising 300–400 students.
- Operating under strict time constraints during sessions.
- Coping with limited equipment and teaching resources.
- Sustaining active participation and engagement throughout demonstrations.

To address these challenges, ALO adopts a strategic and adaptive approach:

- Sessions are carefully planned to maximize limited time and resources.
- Complex optical concepts are simplified through innovative teaching techniques.
- Low-cost, adaptable demonstration tools are employed to enhance accessibility.
- Interactive participation is encouraged to create an engaging and collaborative learning environment.

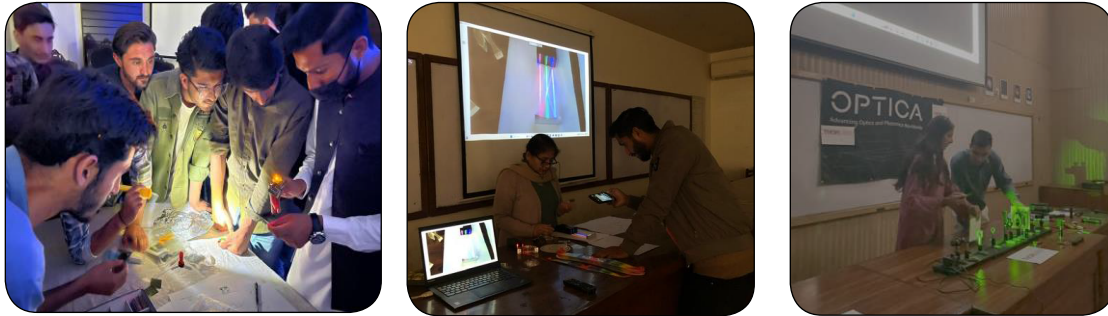


Photo 3: (a) ALO team conducting a hands-on optics session at boys’ campus in International Islamic University, (b) Using Iriun Webcam for live demonstration, (c) ALO members explaining Fourier Optics.

Creative teaching solutions

Recognizing that practical demonstrations are essential for understanding optics, the ALO team devised effective methods to ensure that every participant could observe experiments clearly. By using the Iriun Webcam app to connect mobile cameras to laptops and project live feeds onto large screens, the team enabled real-time, close-up viewing for hundreds of students simultaneously [31].

This simple yet powerful setup transformed logistical barriers into opportunities for inclusion, allowing large audiences to fully experience the excitement of science. The students’ curiosity and enthusiasm remain a source of motivation, fueling ALO’s ongoing commitment to spreading optics education across Pakistan [32].

Optics outreach 2023: A year in review

ALO began 2023 with limited resources and two planned outreach sessions at The Black Hole in Islamabad, aimed at children of different age groups [19]. A breakthrough came in March when the SPIE Outreach Grant was awarded, serving as a catalyst for expansion. This crucial support allowed ALO to extend its efforts to underserved regions of Pakistan, significantly broadening its impact and accessibility.

By the end of 2023, the group had conducted ten outreach activities, including four in remote areas of KPK. The SPIE grant played a pivotal role in overcoming financial constraints, enabling impactful educational initiatives, and empowering students with limited exposure to scientific inquiry. The achievements of 2023 marked a turning point for ALO, reflecting resilience and growth despite challenging economic conditions [23].

Target regions and institutions

Workshops were conducted at recently established women's universities, including:

- University of Swat (Women Campus),
- Women University Mardan,
- Women University Swabi.

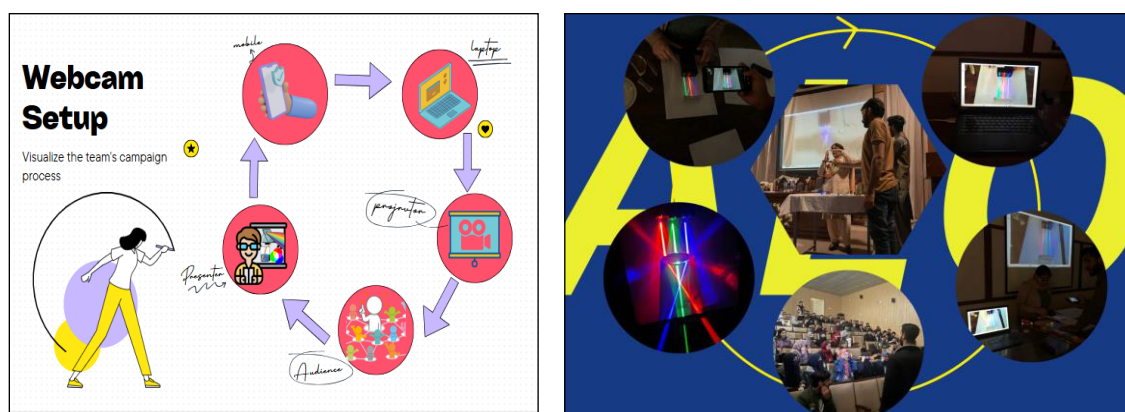


Photo 4. (a) Schematics of Webcam setup, (b) ALO team conducting a hands-on optics demonstration using Iriun Webcam App.

Sessions during the workshops explored fundamental concepts such as reflection, refraction, and diffraction; the operation of optical instruments; and the role of photonics in technologies such as cameras, fiber-optic communication, and biomedical imaging. The impact was profound—many participants were first-generation university students experiencing hands-on scientific activities for the first time. A memorable moment occurred at Women University Swabi, where a student shared:

“We’ve only read about lenses in textbooks. Today, for the first time, I saw how they work.”

This simple yet powerful reflection encapsulates ALO’s mission: to bring science to life and empower young women to envision futures in STEM.

One of our primary goals for 2024 was to extend ALO’s outreach efforts to the northern regions of Pakistan. However, for the third consecutive year, unforeseen circumstances—including adverse weather, technical difficulties, and political instability—hindered our travel and prevented us from conducting activities in those areas.

Despite these setbacks, the ALO Group takes pride in the significant progress made throughout the year. In 2024, we successfully conducted ten optics outreach activities across various educational institutions in Pakistan, with a strong emphasis on engaging girls and young women. These efforts played a vital role in advancing our mission to promote equitable access to quality education and to empower female students who continue to face disproportionate barriers compared to their male peers.

3 ALO Outreach Activities during 2023-2025

Following **Tables 1-3** summarize the outreach activities conducted by ALO group during 2023-2025, in underserved institutions in Pakistan.

Table 1. ALO activities during 2023

S.No	Date	No. of Participants	Venue	Facilitators	Volunteers
1	03-01-2023	25	Quaid-i-Azam University School	Dr. Imrana	Masad Qayyum
2	05-01-2023	25	Quaid-i-Azam University School	Dr Imrana	Masad Qayyum
3	16-05-2023	200	Phy. Depart., Quaid-i-Azam University	Dr Imrana	Masad Qayyum
4	18-05-2023	300	International Islamic University Islamabad	Dr Imrana	Masad Qayyum, Osama bin Ijaz, M Ayaaz
5	22-05-2023	250	Fatima Jinnah Women's University	Dr Imrana	Masad Qayyum, Osama bin Ijaz, M Ayaaz
6	25-05-2023	150	Rawalpindi Women's University	Dr Imrana	Masad Qayyum, Osama bin Ijaz, M Ayaaz
7	13-09-2023	300	Mardan Women's University	Dr Imrana, Dr Raheel Ali	Masad Qayyum, Osama bin Ijaz, M Ayaaz
8	27-09-2023	300	Swabi Women's University	Dr Imrana	Masad Qayyum
9	01-12-2023	350	Quaid-i-Azam University	Dr Imrana, Dr Raheel Ali	Masad Qayyum, Nimra Gazanfer, M Sami Shahid
10	08-12-2023	250	University of Swat	Dr Imrana, Dr M Zahid	Masad Qayyum, Sanwal Farooq

Table 2. ALO activities during 2024

S. No.	Date	Activity Title	Host Institution	Team Members
1	7 March 2024	Follow-up optics activity: Light and laser-based technologies	Fatima Jinnah Women University (FJWU), Islamabad	Sanwal, Hafsa
2	7 May 2024	One-day optics workshop	International Islamic University Islamabad (IIUI), Boys Campus	Sanwal, Masad
3	9 May 2024	Follow-up activity: Light- and light-based technologies	Rawalpindi Women University (RWU)	Sanwal, Masad
4	15 May 2024	One-day hands-on activity	Department of Physics, Quaid-i-Azam University (QAU)	Masad
5	16 May 2024	Optics Fair	Department of Physics, QAU	Masad
6	19 September 2024	IMCG Fall Outreach Activity	Department of Physics, QAU	Sanwal, Masad, Usama
7	11 October 2024	Laser-based hands-on activity	AQ Khan College	Sanwal, Ameen
8	5 November 2024	One-day optics activity: Importance of light in daily life	ALI Trust College	Sanwal, Usama

S. No.	Date	Activity Title	Host Institution	Team Members
9	11 December 2024	Optics workshop and hands-on activity	Department of Physics, QAU	Sanwal, Masad, Usama, Fatima, Kainat, Zeeshan
10	24 December 2024	One-day optics outreach activity	PMAS-Arid Agriculture University, Rawalpindi	Masad, Usama

Expanding Horizons

Building on its success in Khyber Pakhtunkhwa, ALO expanded its reach to geographically challenging and often overlooked regions of Pakistan. While these overlooked areas are remote, they are home to communities with a strong appetite for learning and new scientific exposure.

Working closely with local educators, the ALO team tailored each workshop to match the available infrastructure and academic needs of the students. Although mountainous terrain and long travel routes posed logistical challenges, the passion and active involvement of students and teachers turned each obstacle into an opportunity for deeper engagement.

Table 3. ALO activities during 2025

S. No.	Date	No. of Participants	Venue	Facilitators	Volunteers
1	28-01-2025	130	Mirpur University of Science and Technology (MUST), Mirpur	Dr. Imrana & Dr. Raheel	Masad Qayyum, Raja Sanwal Farooq
2	29-01-2025	60	Beaconhouse School System, Mirpur Campus	Dr. Imrana & Dr. Raheel	Masad Qayyum, Raja Sanwal Farooq
3	29-01-2025	75	Govt. Degree College, Mirpur	Dr. Imrana & Dr. Raheel	Masad Qayyum, Raja Sanwal Farooq
4	19-02-2025	45	Quaid-i-Azam University (QAU), Islamabad	Dr. Imrana & Dr. Raheel	Zeeshan Ali, Fatima Noor, Masad Qayyum, Kainat Hussain
5	09-04-2025	100	Quaid-i-Azam University (QAU), Islamabad	Dr. Imrana, Masad Qayyum	Raja Sanwal Farooq, Zeeshan Ali, M. Usama Jansheir, Fatima Noor
6	28-04-2025	60	Fatima Jinnah Degree College, Gilgit	Dr. Imrana	Masad Qayyum
7	28-04-2025	130	Aga Khan Higher Secondary School for Boys, Gilgit	Dr. Imrana	Masad Qayyum
8	29-04-2025	120	Aga Khan Higher Secondary School for Girls, Hunza	Dr. Imrana	Masad Qayyum
9	30-04-2025	110	Karakoram International University, Gilgit	Dr. Imrana & Dr. Zahid	Masad Qayyum
10	19-07-2025	60	Quaid-i-Azam University (QAU), Islamabad	Zeeshan Ali, Fatima Noor	Raja Sanwal Farooq, M. Usama Jansheir
11	07-10-2025	50	Future World School & College, DHA Phase 5, Islamabad	Dr. Imrana	Raja Sanwal Farooq, M. Usama Jansheir

4 Impact and outcomes of optics outreach

Powerful Ending: Aga Khan Higher Secondary School for Girls, Hunza

The most recent outreach tour concluded at the Aga Khan Higher Secondary School for Girls in Hunza—an inspiring institution situated among the majestic Karakoram mountains and renowned for its academic excellence and strong commitment to women’s empowerment.

Students participated enthusiastically in advanced optics demonstrations on wave–particle duality, interference, fiber-optic communication, and medical imaging. A complementary career guidance session introduced pathways in physics, photonics, and emerging STEM fields.

During a peer-led experiment segment, students confidently demonstrated concepts to one another, taking ownership of their learning environment. After exploring fiber-optic transmission, one student shared:

“I want to become a physicist and come back to teach girls in my village.”

Moments like these reflect the core mission of ALO: to inspire young women to envision themselves as future scientists, educators, and changemakers in their own communities.

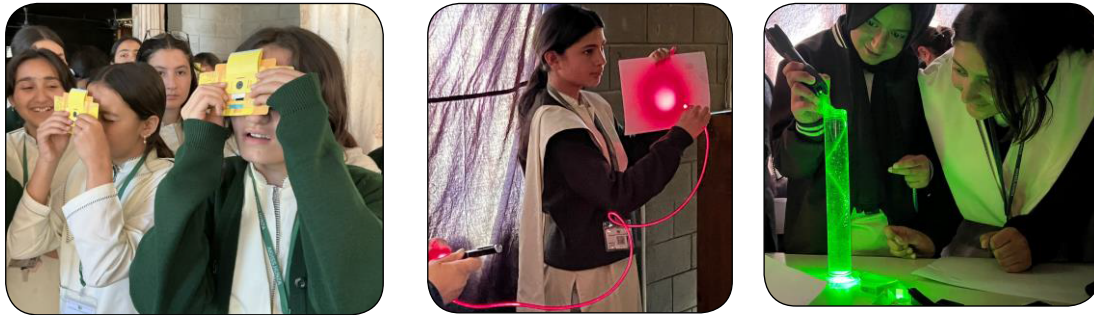


Photo 5. Young girls at Aga Khan higher Secondary school Hunza doing hands-on optics activities.

Data collection and evaluation

Feedback was collected through post-session questionnaires and informal interviews with both students and teachers. The qualitative responses focused on indicators such as:

- Student engagement and curiosity,
- Conceptual understanding of optics,
- Increased motivation to pursue science-related studies.

This continuous evaluation informs improvements in outreach strategies and supports long-term impact assessment.

Reflections and the road ahead

To date, ALO has reached hundreds of students through more than 90 hands-on optics sessions. For many participants, this marked their first opportunity to explore physics through interactive experimentation rather than memorization-focused instruction.

The success of ALO lies not only in introducing new scientific concepts but in reshaping how students perceive science—as an exciting, creative, and accessible field. By emphasizing inquiry-based learning, the initiative challenges deeply rooted stereotypes that often discourage young women from pursuing STEM careers.

Nevertheless, challenges remain:

- Limited funding restricts travel to more distant regions and the development of additional learning resources,

- Cultural constraints sometimes limit female student participation in conservative communities,
- A shortage of trained science educators in rural schools affects continuity after outreach visits,

To overcome these hurdles, ALO is working toward:

- Teacher training modules to build capacity within local institutions,
- Low-cost optical kits to enable sustained hands-on learning,
- Stronger national and international partnerships, including with ICTP, SPIE, Optica, and the International Commission for Optics (ICO), to scale outreach efforts

These strategies aim to establish a self-sustaining, community-rooted model of science education, ensuring long-term benefits beyond the initial intervention.

Summary

ALO initiative demonstrates that measurable progress toward gender equity in STEM education can be achieved through targeted, context-aware outreach. By harnessing the universal appeal and accessibility of light, ALO has made science visible, understandable, and exciting for thousands of girls across Pakistan—helping to build confidence and foster scientific ambition.

ALO's continued collaboration with international organizations, combined with strong academic leadership at the national level, exemplifies how grassroots initiatives can complement broader educational reforms. Sustained investment in such programs can play an essential role in strengthening Pakistan's STEM pipeline, promoting gender-inclusive education, and cultivating future scientists and innovators.

Light symbolizes knowledge, clarity, and opportunity. Through ALO, we are not only teaching the science of light but also illuminating pathways to empowerment and equality. In spirit, this work continues the legacy of Professor Galliano Denardo, whose belief in the transformative power of education continues to guide every ray of light we share. Our vision remains clear and unwavering: no girl—regardless of her geography or circumstances—should be left in the dark when it comes to science.

Acknowledgments

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