Review of the initiatives in education and training tailored to industry needs over ten years of the SPIE Optics Education and Outreach Conference

Matthew T. Posner[a], Gabrielle Thériault[b], Patrick Franzen[c], Anne-Sophie Poulin-Girard[d], G. Groot Gregory[e]

[a]Excelitas Technologies Canada, Vaudreuil-Dorion, QC, Canada
[b]Gentec Electro-Optics Inc., Québec City, QC, Canada
[c]SPIE, Bellingham, WA, USA
[d]Université Laval, Québec City, QC, Canada
[e]Synopsys, Malborough, MA, USA

ABSTRACT

Initiatives in education and training tailored to industry needs have been a core part of the bi-annual SPIE Optics Education and Outreach conference, accounting for over 50% of papers since its inception in 2010. In this paper, the authors explore whether this conference has been useful to the readership by reviewing the contributions to this meeting for industry-oriented activities. Accounting for this scope, a bibliographic review of the literature of all five proceedings of OP301 is presented to describe the participants in terms of their affiliations and background, the proceedings' taxonomy, and the metrics for downloads and citations. An integrative review will support this report to present lessons learned in six key areas of (1) technician training, (2) continuous education and training in industry, (3) in-company training and internships, (4) local and regional economic development through optics and photonics education and research, (5) progress on accreditation and certification, and (6) programs in innovation and entrepreneurship. The findings will be used to evaluate trends in formal and informal methods for industry-related programs and make recommendations for areas of potential focus for future meetings to continue serving wider segments of the community.

Keywords: Industry training, Review, Accreditation, Formal education, Technician training, Continuous education.

1. INTRODUCTION

Initiatives in education and training tailored to industry needs have been a core part of the bi-annual Optics Education and Outreach conference. Has this conference and its proceedings been useful to the community? The present paper sets out to review this segment of the literature, to capture metrics, and assess trends in this field of education. In §2, the background of the conference is presented, including history, reach and engagement. In §3, bibliographic search methods for identifying papers within scope are described, to then support a topical review presented in §4. Finally, future directions for this conference and wider engagement potential are proposed in §5 based on these findings.

2. BACKGROUND

There is a long history of education and training initiatives aligned with industry needs across the optics and photonics literature; for instance, the earliest proceeding recorded with a keyword combination of "optics", "industry" and "education" is a course on basic optics and instrumentation for technical personnel from 1962[1]. The International Education and Training in Optics and Photonics (ETOP) conference has been a platform to report such initiatives over its

*mp1g09@alumni.soton.ac.uk, https://spie.org/profile/dr.matthew.posner

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history[2]. Similar topics have been found under various tracks of the conference reviewed; prior to reviewing these, a general background of the conference is described in this section.

2.1 A brief history leading to the SPIE Optics Education and Outreach conference

The Optical Education and Outreach conference evolved over 15 years, starting with a serendipitous oral presentation presented in 2005 by Prof. Julie L. Bentley[3], showing how a common lens design program, given as a midterm example, worked in formal education. This one isolated paper submitted to the Novel Optical Systems Design and Optimization (OP304) conference led to annual sessions in the same conference over subsequent years. The International Society of Optics and Photonics (SPIE), regional consortiums, as well as other organizations and individuals were conducting outreach activities to enhance optical awareness and education. These efforts provided authors for the handful of talks that filled the sessions offered in the OP304 conference, providing a route to present less traditional optics-related talks to broaden the diversity of information in the literature.

With these known initiatives, the assumption was that many attendees for the technical conference were evangelists for formal and informal optics education, beyond the research professor and graduate student. This was particularly true of the many SPIE student chapters active in outreach around the world. Many of the student leaders converge for the SPIE annual meeting and could contribute to the informational sharing, thus reducing the need to discover and reinvent the tools used to share optics in the community. After five years of sessions on education and 15 presentations at OP304, a stand-alone conference, Optics Education and Outreach (formally OP301, and abbreviated OEO in this manuscript), was created with the purpose of increasing the sharing and archiving the diverse efforts surrounding optics, with the added benefit of all paper provided as open access. The first conference took place in 2010 with 24 submissions. The initial success allowed the conference to continue and has been repeated every two years. The biannual schedule was set to complement the ETOP conference, held in odd years with a similar topic focus, although generally not in conjunction with a predominantly technical meeting. Metrics on the engagement at OEO are presented in the following sub-section.

2.2 Engagement with Optics Education and Outreach

Data on the conference engagement was provided by the SPIE. In total, 441 authors from 31 countries have contributed 190 papers to the conference proceedings. In-person attendance has been of 2,338 people in five conferences, representing an average of 24 people per paper presented. Professional affiliation and gender are not tracked as part of the storage of the data and were not considered in this classification. More than 103 author-defined keywords have been used across all proceedings, with the terms of “Optics”, “Photonics”, “Education”, “Outreach”, and “IYL2015” (indicating the 2015 **I**nternational **Y**ear of **L**ight) being the most highly represented – see Figure 1 for a weighted collection of the keywords.

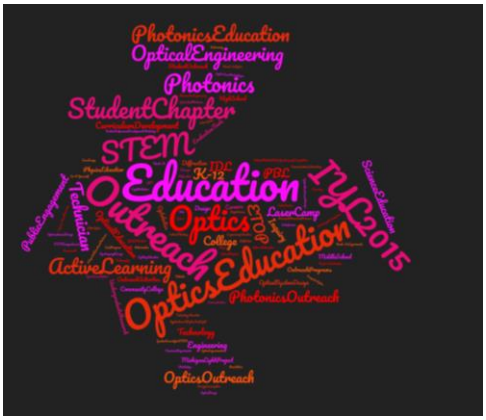
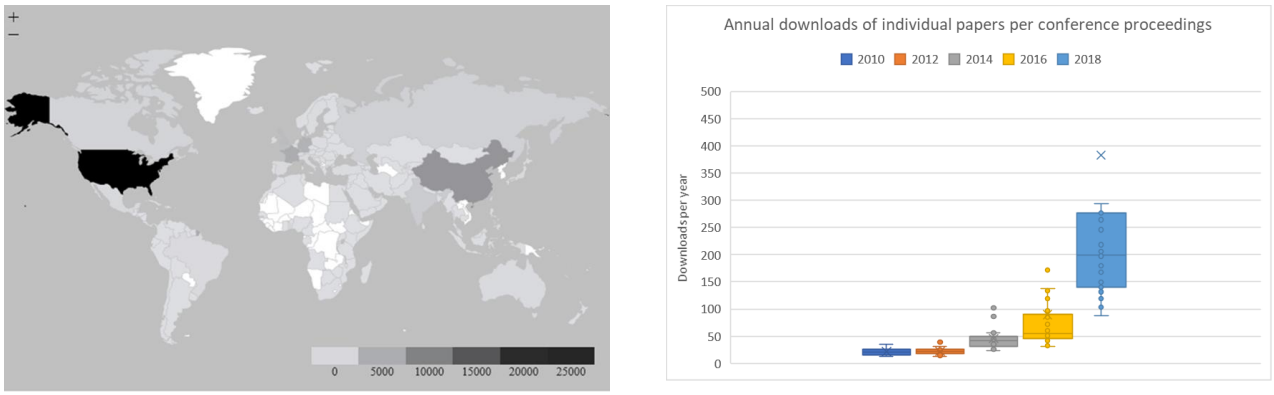


Figure 1. Weighted word map of author-defined keywords from manuscripts of OEO conferences 2010-2018.

The manuscripts and presentations have been very popular in a post-conference setting, with more than 53,000 downloads of proceedings as of March 2020. The number of downloads for the regions of North America (22k), Europe (16.9k), and Asia (11.4k) account for close to 95% of total downloads, compared to other regions of Africa (0.5k), Middle East (0.7k), South Pacific (0.7k) and the Caribbean, Central & South America (0.9k) – see Figure 2 (a). The number of downloads per conference year has also increased over the history of the conference, with the median annual

download per paper of 200 for those in the 2018 proceedings, compared to a range of 25-50 median annual download per paper in prior years – see Figure 2 (b). The data obtained before 2018 are, however, likely to be a conservatively low estimate of this impact due to the SPIE using database platforms with less capabilities.



(a) (b)

Figure 2. Post-conference reach of the meeting. (a) Downloads per country of conference proceedings, with regional breakdown noted in text. (b) Annual downloads of individual papers for each year of the conference.

At the time of writing, topic areas for initiatives aligned with industry needs have formed the basis for the call for papers for the 2020 SPIE Optics Education and Outreach conference. The sub-topics are based on a similar track designed at ETOP in 2019, which covered 6 areas of focus, namely (1) technician training, (2) continuous education and training in industry, (3) in-company training and internships, (4) local and regional economic development through optics and photonics education and research, (5) progress on accreditation and certification, and (6) programs in innovation and entrepreneurship. The implementation was facilitated by overlap in the communities and leadership engaged in these meetings. The methods for a retro-active classification of OEO contributions will be presented in §3.

3. CLASSICATION OF THE INDUSTRY TRACK

The following section describes the design of bibliographic search methods and their application to the retroactive classification of existing literature around the six topic areas described previously.

3.1 Bibliographic search methods

The SPIE Digital Library (spiedigitallibrary.org) was employed to research papers in the five proceedings of OEO (#7783, 8481, 9188, 9946, 10741). A list of terms was designed to identify papers within the scope of the review – see Table 1 for preliminary search terms. No clear strategy was found to identify terms linked to the topic "local and regional economic development" due to the broad area covered. A secondary search was carried out to identify papers with links to industry (search term "industr*"). Search methods 1 and 2 returned 40 and 73 results, respectively 27% and 50% of all papers, indicating a broader potential segment of the literature for initiatives aligned with industry needs.

Table 1. Search strategy to identify paper within scope

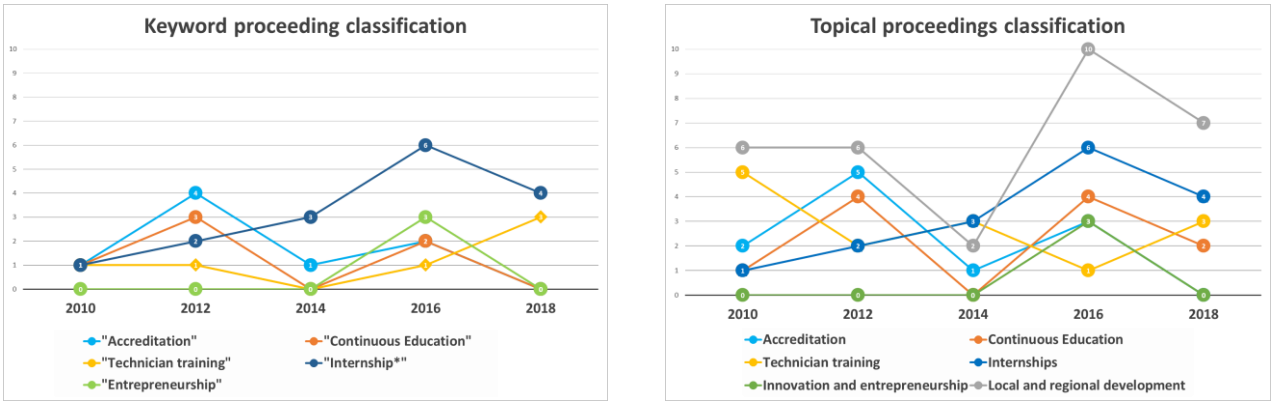
Sub-topics	***Search terms***
(1) technician training	(1) "technician training"
(2) continuous education and training in industry	(2) "continuous education"
(3) in-company training and internships	(3) "internship*"
(4) local and regional economic development	(4) n/a
(5) progress on accreditation and certification,	(5) "accreditation"
(6) programs in innovation and entrepreneurship	(6) "entrepreneurship"

A manual search methodology was therefore employed. A random sample of 36 papers (25%) of the proceedings were selected for evaluating the approach. Each abstract was individually reviewed by 3 people, which assessed whether these should be shortlisted to the Industry track; if so, the papers were reviewed in depth and categorized based on the interpretation of the sub-topics listed in Table 1. All three reviewers agreed that 30% of articles would be in scope, which is comparable to the 27% identified using the terms in Table 1. In addition, this search methodology identified papers related to the sub-topic "*local and regional economic development*". Another 36% of the papers were open for interpretation, with the highest area of uncertainty associated to the sub-topics of Continuous Education, and Local & Regional economic development. There were large variations between the rates of articles that reviewers considered to be within the scope based on reviews of the abstract, justifying a need for a more detailed analysis. All papers of the proceedings were therefore reviewed in depth and classified into each category. Mendeley Desktop (V1.19.4) was used to store and classify proceedings, and papers in all six topic areas were identified.

A supplementary taxonomy analysis was carried out to assess whether automated classification methods could be employed. Analysis was run by SPIE on 11 papers in each of the three following sub-topics: (1) technician training, (2) accreditation, and (3) local and regional economic development. The automated study provided a set of weighted topical terms and of technology areas; these are associated to a pre-established list proprietary of the SPIE Digital Library engine. Results from the automated and manual classifications, as well as the terminology analysis, are presented in the next section.

3.2 Overview of results.

The classification results for both the automated and manual methods are shown in Figure 3 (a) and Figure 3 (b), respectively. A significant amount of overlap between sub-topics was found and is not accounted for in Figure 3. The number of papers of proceedings #9946 (2016) was larger compared to other years due to an increased focus of scope and submissions related to activities for the 2015 International Year of Light. This global public outreach and advocacy event raised awareness of the importance of optics and photonics to regional and economic development; both volume and awareness may account for this spike. The details of each paper as well as trends over time will be presented as part of the topical review of §4.



(a) (b)

Figure 3. Overview of (a) automated, and (b) manual classification of OEO papers within sub-topics of the industry track.

The analysis of the taxonomy did not yield results to help define keywords to assist in automating search methodologies of the sub-topics of Table 1. Indeed, the tool is designed to assess more traditional technical areas and does not provide an indication on subject areas that may interest an audience of formal and informal educators that this conference usually engages with. Many of the terms returned reflect optics concepts at a level pertinent to the audience being addressed.

Insights into trends for education programs can nevertheless be gained from reviewing the terminology identified. To illustrate this, the top 10 topics for papers in the technician training programs are summarized in Figure 4. Broad technical areas that are widely accepted as essential for technical training in the literature can be found, such as computer-aided design (CAD) and other areas of general optical sciences and engineering. The top three terms identified

were (1) Photonics, (2) Optoelectronics, and (3) Standards development. Terms (1) and (2) are consistent with the results found for taxonomy in other general areas. Standards development is a non-technical term, suggesting that this theme is possibly a higher-level than the sub-topic as part of the industry track described previously; this will be validated in the following topical review. The papers in this field are mainly from North America, so extending to larger datasets may provide interesting knowledge on regional variation in focus areas for technology and topics. This is, however, beyond the scope of the topical review that will be presented in §4.

Figure 4. Top 10 fields from the analysis of papers related to technician training.

4. TOPICAL REVIEW

A topical review of the literature based on the 6 focus areas of the Industry track is described in detail in the following section, noting contributions and trends associated to each of these.

4.1 Progress on Accreditation, Standards and Certification

Reports on Accreditation and Certification are well identified with the taxonomy described in §3. A significant number of reports in 2010-2012 assessed the role of the Accreditation Board of Engineering and Technology (ABET) in the certification of formal education programs with optics and photonics components, primarily focused on education programs in North America[4]. Notable programs at Rose-Hulman Institute of Technology, featuring internship "capstone" projects[5,6] and formal curriculum development[7], provide insight into linking accreditation to optics and photonics courses.

Aside from ABET, there have been significant progress in developing national technical training certificates, with notable examples of the National Center for Optics and Photonics Education (OPTEC)[8], and the Electronics Technician Association Intenational[9]. These are highlighted here as they provide insight on the process, concerning the inclusion of stakeholders from industry, academia, government, and not-for-profit associations. The content on technician training programs will be described in a later part of this section.

Professional societies play a role in the certification process by providing a platform to amplifying informal education initiatives, in the aim of greater and recognized adoption[10]. The topics of reports have recently shifted to document efforts to align K-12 programs, and international equivalent, to national[11,12] and regional standards[13]. Portable and accessible informal education kits, such as Dumpster Optics, provide routes to be adapted and align to local curricula, which is as a necessary step for Accreditation and Certification[14].

4.2 Continuous Education, and Training for Academia and Industry

The focus of Continuous Education reports has been on programs, toolkits, and resources to enable continuous education for youths and professionals seeking to enter optics and photonics at various stages of their career. Advanced modules aimed at graduate-level researchers or experienced industry professionals have been reported[7], in line with the curriculum development described previously. Teacher development carried out in conjunction with formal education programs are an important element to build the appreciation of professional educators that can have an impact on youths pursuit of STEM subjects[15].

On another side of the spectrum, portable kits, such as low-cost optical microscope, have been used to reach many education and public places[16]; these provide a useful means to driving technical and hand-made projects, similar to the Maker Learning phenomena forming a growing part of education literature[17]. Increasing the accessibility and availability of relevant training programs and tools is central to many other reports, ranging from remote robotics programs[18] and

hands-on photonics experiments[19,20] reaching participants across North America. Text book design[21] has also been reported as a means to increase reach and accessibility of technical knowledge.

4.3 Innovation and Entrepreneurship programs

Innovation and entrepreneurship programs have taken an important place in STEM education[22], although only a few reports have been recorded in the proceedings of OEO. These manuscripts reveal trends set in education establishments to promote advancement of research with innovation-oriented education, as well as creating spaces for start-ups and incubators. Two case studies from the ITMO University, Russia, illustrate the combination of formal[12] and informal[23] education environments in developing these ecosystems. Such centers require a balance of technical and management skills to enable successful entrepreneurial activity. The French Association of Optics Industries (ASERFO) provides a comprehensive illustration of programs that can be developed to address core technical, management and professional development skills. They place a big emphasis on looking out through entrepreneurship modules and creating a regional ecosystem between key players, namely centers for education, research, innovation and industry[24].

4.4 In-company training and internships

In-company training and internships programs reported as part of OEO are predominantly linked to formal education program requirements. Specific examples showing high-level of interaction between the education and private sectors are exemplified in dual programs at the University of the Federal Armed Forces, Hamburg, Germany. These are designed to have more pronounced overlap of activities in academia and industry for students and professionals, to further facilitate integration of professional and specialist skills for career advancement. These offer interesting prospects to alternatives to continuous education; details of these programs' structure and balance[25] as well as internships[26] are described.

Methods and benefits for the incorporation of internships into formal programs are globally recognized at university-level [15,27–29], in technician training centres[30–32] for a range of students, and other training centers such as the Air Force Research Laboratory, USA[33]. There are no reports on the international movement of the workforce facilitated through in-company training, although the added-value of international movement to education has been noted in the context of university research internships[34]. Overall, there is a high-perceived value in company-focused training for technical roles and thus a natural overlap with reports for technician training programs, which are described in the following section.

4.5 Programs focused on technicians

Presentations on the need for a technical workforce to meet the industry growth have been discussed throughout the conference's history. Early presentations reviewed strategies and implementations for developing regional-level needs of the industry in Ontario[35]. Reports from the USA describe in depth programs developed at a regional level at Baker College, Michigan, USA[31,36], as well as the national initiative and operations in the USA of OPTEC discussed earlier[8]. Few reports have been presented from outside of North America: these include those of the University of the Federal Armed Forces in Hamburg described previously[25,26]. A generalized technical education combining hands-on and theoretical skills is required, as was described in the terminology analysis of §3.

Technical course content and pedagogy implementation within formal education have been presented. One notable solution for increased student engagement and success is utilizing problem-based learning at a community college adapted for technician students[37]. Further accounts of industry-driven capstone projects done in conjunction with placements have been noted as beneficial[30].

A portion of papers report on professional development and career growth programs driven by technicians in training, using platforms such as student[38,39] and institutional[40,41] organizations in Community Colleges. These note the importance of professional development programs through these community driven initiatives, which has been discussed elsewhere in the optics and photonics literature[42].

4.6 Local and regional economic development through optics and photonics development and research

The sub-theme lends itself to a very broad interpretation, in part due to challenges in defining a taxonomy for initiatives that often present entry-level topics for optics and photonics education. A significant number of these initiatives to boost local and regional development overlap with other areas of activities due to the regional aspect of the work[11,15,16,28,32,35,40,43]; the reader is thus referred to previous sections for more in-depth discussion on these in the scope of the review.

A key factor of success to local and regional development is stakeholder engagement with educators. Case studies of strategies for engagement are reported for a rich variety of events, ranging from public art structures[44], education workshops for local communities[45,46], competitions and judging[47], and resources development on careers in photonics[48]. These offer interesting insights to parties wishing to support through funding, engagement, or other means. Advocacy, with industry partners gained a lot of attention in the literature in the wake of dedicated tracks at OEO to report on initiatives for the UNESCO International Year and Day of Light. Industry sponsorship and investment into programs[49,50] as well and engagement models and tools to offer visibility and engagement routes[19,51] are reported. Another strategy for benefitting local and regional economic development is through funding of kits; examples range from the distribution of spectrophotometers in 11 countries in the region of Africa[52], holography kits[53], as well are more general optics and photonics kits for educators, as described in the Photonics Explorer program[54,55].

5. OUTLOOK

The paper has presented a historical overview of the SPIE Optics Education and Outreach conference, along with a topical review of the literature for initiatives aligned to industry needs. These reports can be found extensively across all proceedings, and this despite no dedicated track for this meeting from 2010-2018. The initiatives englobe a broad range of activities targeted at individuals (re)entering the field at different stages of their lives; this is consistent with some of the wider goals of the conference alluded to in §2, for sharing and archiving the diverse efforts englobing both formal and informal education methods and to "educate the next generation of scientists and engineers"[56].

The current topical review falls short of a rigorous scoping review, but is adequate given the scope and volume of the literature considered; formal frameworks[57] could be considered for a broader review of the education and training initiatives aligned to industry needs. There have also been limitations in the identification of the segments contributing to this body of literature; a more systematic organisational effort for classification of areas such as author gender and affiliation could help identify under-served segments in the authorship and community. Strengthening collaboration with ETOP initiatives will provide annual feedback for more regular exchange of ideas and topics, as well as obtaining regional reports from a broader audience. With this future in mind, suggestions for adapting the "*Industry track*" through retaining topics, expanding the scope and redirecting higher-level content will be described here and are summarized in Table 2.

The overlap between formal education system and industry needs is well documented in the context of Standards Development. Implementation of accreditation and certification programs has led to greater experience in providing other models of continuous education, training for academia and industry, as well as local and regional development. These themes in some way go beyond this industry track, so redirecting these into other topical areas may maintain the appeal of the meeting with educators involved in program design in formal and informal education.

New approaches to implementing programs, such as Maker Learning and Entrepreneurship programs, have been reported. There is great potential for growth in the sharing of this knowledge by maintaining call for papers in these areas. Solicitations for reports on high-level commercial technology for outreach and in-company training may be of interest to a larger segment of the industry-based community, such as providers of systems for Augmented Reality, LIDAR and other technology areas present at the co-located SPIE Optics + Photonics congress.

Successful initiatives tend to demonstrate cohesive stakeholder involvement, combining expertise and passion to enable successive activities. Building formal curriculum and career development programs exemplify this type of effort. These have been noted to "*increase awareness about optics and photonics with local companies and create favorable conditions for STEM-related successes*[58]." In this respect, vision and goal setting is crucial in bringing new ideas, creating long-lasting partnerships at all levels, as well as achieving a healthy balance between activities, work, and life.

Table 2. Guidelines for future directions of the industry track.

Retain	*Expand*	*Redirect*
In-company training and internships Programs focused on technicians Programs in innovation and entrepreneurship	Career development in industry Outreach with applied technology Formal curriculum built in partnership with industry	Continuous education Standards development Local and regional economic development

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REFERENCES

[1] Northrop Grumman., "Basic Optics and Optical Instrumentation," Image Enhanc., 1 (1963).
[2] Robinson, K. and Lakshminarayanan, V., "ETOP: a retrospective study," Proc. SPIE 9793, Educ. Train. Opt. Photonics ETOP 2015 **9793**, 9793–03 (2015).
[3] Bentley, J. L., "Thirty different views of a lens design solution space: a good example for teaching students how to design and not to design a lens," Nov. Opt. Syst. Des. Optim. VIII **5875**, J. M. Sasian, R. J. Koshel, and R. C. Juergens, Eds., 58750C, SPIE (2005).
[4] Shoop, B. L. and Robinson, K. B., "ABET accreditation and optics and photonics engineering: an association whose time has come," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848107, SPIE (2012).
[5] Bunch, R. M., Lepkowicz, R. S. and Granieri, S. C., "Rethinking optical engineering capstone design experience," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 77830O-77830O – 6, SPIE (2010).
[6] Bunch, R. M., Leisher, P. O. and Granieri, S. C., "Optical engineering capstone design projects with industry sponsors," Opt. Educ. Outreach III **9188**, G. G. Gregory, Ed., 918804, SPIE (2014).
[7] Bunch, R. M., Joenathan, C., Connor, K. and Chouikha, M., "Modules to enhance smart lighting education," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 84810B, SPIE (2012).
[8] Souders, J. and Hull, D., "Preparing technicians for photonics industries and organizations," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848104, SPIE (2012).
[9] Woodward, W. R., "Meeting evolving technology education challenges in photonics and optics," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848108, SPIE (2012).
[10] Nantel, M. and Robinson, K., "On the role of professional societies in optics and photonics education," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848102, SPIE (2012).
[11] Lopez, C. and Solano, C., "Optics workshops designed to preschool children (age 3 to 6 years)," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994617, SPIE (2016).
[12] Voznesenskaya, A., Bougrov, V., Kozlov, S. and Vasilev, V., "ITMO Photonics: center of excellence," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460V, SPIE (2016).
[13] Magnani, N. and Blanchette Smith, M. Lou., "Light: connecting to the Connecticut science standards," Opt. Educ. Outreach **7783**(August 2010), 778307-778307–778310 (2010).
[14] Donnelly, J., Magnani, N. and Robinson, K., "Dumpster Optics: teaching and learning optics without a kit," Opt. Educ. Outreach IV **9946**, 99460G, SPIE (2016).
[15] Gilchrist, P. O., Conover, B., Bowles, T., DeDeugd, C. and Hilliard-Clark, J., "Piloting photonics curriculum in staff development," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 778306-778306–778307, SPIE (2010).
[16] Anselmi, F., Grier, Z., Soddu, M. F., Kenyatta, N., Odame, S. A., Sanders, J. I. and Wright, L. P., "A low-cost do-it-yourself microscope kit for hands-on science education," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 19, SPIE (2018).
[17] Lee, M. J. W., "Guest Editorial Special Issue on Maker Learning in Computer Science and Engineering Education," IEEE Trans. Educ. **60**(1), 38–39 (2017).
[18] Luciano, S. C. and Kost, A. R., "Robotic laboratory for distance education," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460O, SPIE (2016).
[19] Silberman, D. M., Cartland, R., Monacelli, B. and Whitmore, D., "Informal optics education and outreach programs in Southern California," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 77830J-77830J – 8, SPIE (2010).
[20] Silberman, D. M., Rowe, T. S., Jo, J. and Dimas, D., "New teaching methods in use at UC Irvine's optical engineering and instrument design programs," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848103, SPIE (2012).
[21] Hecht, J., Hecht, D., Chowdary, A. and Massa, N., "Re-inventing the fiber-optic textbook: a proposal," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460M, SPIE (2016).
[22] Schuelke-Leech, B., "Engineering Entrepreneurship Teaching and Practice in the United States and Canada,"

IEEE Trans. Eng. Manag., 1–20 (2020).
[23] Ivashchenko, M., Bodrov, K. and Tolstoba, N., "Educational area for learning of optics and technologies: union of open laboratories of ideas, methods and practices (OLIMP)," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994613, SPIE (2016).
[24] Mazuray, L. and Balembois, F., "ASERFO, a concrete example of collaboration between industries and academia to develop students' skills in know-how, entrepreneurship and behavior," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460H, SPIE (2016).
[25] Hahlweg, C. and Rothe, H., "Optics and optronics in university courses for officers of the Federal Armed Forces - special curricula and hands-on lessons vs. academic requirements," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460J, SPIE (2016).
[26] Brennförder, J. and Hahlweg, C. F., "Implementing optics courses in dual engineering university programs: challenges and perspectives," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 3, SPIE (2018).
[27] Buranasiri, P., "Optics and communication technology major of physics undergraduate degree at King Mongkut's Institute of Technology Ladkrabang," Opt. Educ. Outreach III **9188**, G. G. Gregory, Ed., 91880A, SPIE (2014).
[28] Diaz, A., Friedman, J. S., Saltares, R., Gordillo, R. and Trujillo, E., "Development of a photonics outreach and education program through partnerships at Universidad Metropolitana for Puerto Rico and the IYL," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994606, SPIE (2016).
[29] Bakholdin, A., Bougrov, V., Voznesenskaya, A. and Ezhova, K., "Advanced interdisciplinary undergraduate program: light engineering," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994612, SPIE (2016).
[30] Donnelly, J., Massa, N. M., Tinker, F. and Tomasi, G., "Industry-based projects in photonics technician education," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 848106, SPIE (2012).
[31] Sala, A. L., "Developing a photonics education program at college level from the ground up," Opt. Educ. Outreach III **9188**, G. G. Gregory, Ed., 918803, SPIE (2014).
[32] Friedman, J. S., Diaz, A., Trujillo, E., Saltares, R., Floran, L. and Gordillo, R., "Photonics workforce education and development in Puerto Rico," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460K, SPIE (2016).
[33] Spencer, M. F., Atencio, I. J., McCullough, J. A. and Hwang, E. S., "The AFRL Scholars Program: a STEM-based summer internship initiative," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460E, SPIE (2016).
[34] Kassu, A., Farley, C., Mills, J., Sharma, A. and Ruffin, P., "Impact of undergraduate research participation in characterization of materials," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 5, SPIE (2018).
[35] Nantel, M., "Ten years of photonics education at the college level in Ontario: results and by-products," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 77830P-77830P – 11, SPIE (2010).
[36] Sala, A. L., "Photonics technician education in Michigan: an update," 16 September 2018, 4, SPIE-Intl Soc Optical Eng.
[37] Donnelly, J., Massa, N. M., Dischino, M. and Hanes, F., "Implementation stories from the PHOTON PBL project," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 778305-778305–778310, SPIE (2010).
[38] Magnani, N. J. and Donnelly, J., "A colorful approach to teaching optics," Opt. Educ. Outreach III **9188**, G. G. Gregory, Ed., 91880L, SPIE (2014).
[39] Karis, I. and Wiedholz, C. T., "Connecting with the community LASER-TEC and CCCC SPIE Student Chapter Outreach initiative (Conference Presentation)," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 20, SPIE (2018).
[40] Tourangeau, D. and Simoneau, J., "Stories from Laser Camp: outreach activities for kids," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 77830L-77830L – 8, SPIE (2010).
[41] Adams, A. M. and Beasley, G., "IYL 2015 celebrations," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460A, SPIE (2016).
[42] Wong, N. H. L., Posner, M. T. and John, P. V., "The Lightwave Programme and Roadshow : An Overview and Update," Proc. SPIE 9793 **97932V**, 1–16 (2015).
[43] Solano, C. E. and López, C. M., "Optics training programs for primary teachers: using the new Mexican education program," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 6, SPIE-Intl Soc Optical Eng (2018).
[44] Rilling, M., Gauthier, J.-C., Côté, A., Frayssinous, C., Allain, G., Gouin, S., Magnan, S., Duval, S., Michaud-Belleau, V., Jobin, F. and Dallaire, X., "An optics and photonics exhibit that reunites, educates and, engages: a meeting with light," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 9, SPIE-Intl Soc Optical Eng (2018).
[45] Solano, C., Campos, A. and Leon, E., "Science workshops in isolated communities in the state of Guanajuato, México," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 84810P, SPIE (2012).

[46] Leonard, M. J., Hannahoe, R. M. and Nollmeyer, G. E., "Turning Eyes to the Big Sky project: learning optics in middle school," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 84810G, SPIE (2012).
[47] Larimer, R. M., DesJardins, A., Shaw, J. A., Kankelborg, C. C., Palmer, C., Springer, L., Key, J., Knighton, W. B., Repasky, K. S., Pust, N. J., Hobish, M. K., Wilson, E. W., Fitzgerald, C., Fitzgerald, R., Trickel, T., Jensen, C., Dorsett, S., Anderson, M., Boger, J., et al., "National Student Solar Spectrograph Competition overview," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 84810Z, SPIE (2012).
[48] Poulin-Girard, A.-S., Gingras, F., Zambon, V. and Thériault, G., "Engaging the optics community in the development of informative, accessible resources focusing on careers," Opt. Educ. Outreach III **9188**, G. G. Gregory, Ed., 91880H, SPIE (2014).
[49] Sicardi-Segade, A., Campos-Mejía, A. and Solano, C., "Development of activities to promote the interest in science and technology in elementary and middle school students," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994616, SPIE (2016).
[50] Sala, A. L., Dreyer, E. F. C., Aku-Leh, C., Jones, T., Nees, J. A. and Smith, A., "Celebrating the International Year of Light in Michigan," Proc. SPIE **9946**, 994602–994607 (2016).
[51] Davies, R. and Shore, K. A., "Inspiration, imagination and implementation: International Year of Light activities of the Photonics Academy of Wales at Bangor (PAWB)," Proc. SPIE **9946**, 994605–994614 (2016).
[52] Forbes, P. B. C., "Seeing the light: The SpecUP educational spectrophotometer," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460Z, SPIE (2016).
[53] Nees, J., Aku-Leh, C., Jones, T., Sala, A. L., Smith, A. and Dreyer, E. F. C., "International Year of Light in Michigan: outdoor holography," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 99460B, SPIE (2016).
[54] Prasad, A., Debaes, N., Cords, N., Fischer, R., Vlekken, J., Euler, M. and Thienpont, H., "Photonics Explorer: revolutionizing photonics in the classroom," Opt. Educ. Outreach II **8481**, G. G. Gregory, Ed., 84810H, SPIE (2012).
[55] Sánchez-López, M. del M., García-Martínez, P., Espinosa, R., Carnicer, J., Arias, J. and Moreno, I., "Outreach activities on light science and technology at TecnOpto-UMH during the International Year of Light," Opt. Educ. Outreach IV **9946**, G. G. Gregory, Ed., 994604, SPIE (2016).
[56] SPIE, P. of., "Front Matter: Volume 7783," Opt. Educ. Outreach **7783**, G. G. Gregory, Ed., 778301-778301–778307, SPIE (2010).
[57] Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., et al., "PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation," Ann. Intern. Med. **169**(7), 467–473 (2018).
[58] Poulin-Girard, A.-S., Boudreau, G., Landry, J., Guérard, M.-A., Thériault, G., April, A. and Veillette, A., "Ten years of photonic games: lessons earnt," Opt. Educ. Outreach V **10741**, G. G. Gregory, Ed., 17, SPIE (2018).