A study of the skills required by the Canadian photonics industry

Daniel Hutama[a,b], Harry Ao Cai[c], Ozan W. Oner[a,b], Mustafa Hammood[d], Lukas Chrostowski[d], Jeff Lundeen[b], Ksenia Dolgaleva[a,b], Dan Deptuck[e], Madison Rilling[f], and Matthew Posner[f]

[a]School of Electrical & Computer Engineering, University of Ottawa, Ottawa, Canada
[b]Department of Physics, University of Ottawa, Ottawa, Canada
[c]Department of Mechanical & Industrial Engineering, University of Toronto, Toronto, Canada
[d]Department of Electrical & Computer Engineering, University of British Columbia, Vancouver, Canada
[e]CMC Microsystems, Kingston, Canada
[f]Optonique, Québec, Canada

ABSTRACT

This study provides a comprehensive and up-to-date portrait of the skills desired by the Canadian photonics industry. To accomplish this, we investigate Canadian job postings on popular employment websites in the fields of optics and photonics to characterize clusters of skills in high demand. We supplement this investigation with an analysis of responses to a questionnaire distributed to over 300 companies with Canadian operations. We present the resulting information in a manner to support evidence-based policy decisions, such as recommendations for improvements to educational programs to better meet the training needs conveyed by the Canadian photonics industry.

Keywords: Workforce Training, Photonics, Optics, Quantum, Curriculum Development, Public Policy

1. INTRODUCTION

The rapidly evolving field of photonics has a wide range of applications in areas such as telecommunications, computing, healthcare, energy, defense, and quantum technologies.[1,2] The sector has been recognised since 2009 as a "key-enabling technology" by the European Commission,[3] and has received significant government funding of education and training programs around the world.[4,5] The development of educational programs requires a multi-disciplinary framework, with the transition to the job market being one key consideration.[6] A large volume of literature has investigated activities to address the evolving needs of the industry. Efforts have been made to record advances for the photonics industry,[7,8] as well for key application sectors enabled by photonics, such as quantum technologies.[9] Industry consultations have been used as a means to inform the development of post-secondary education programs,[10,11] with further initiatives focused on tackling the ongoing lack of critical technologist roles.[12–14] There are no recent systematic studies in Canada, despite a significant track record of engagement with industry stakeholders via foundational planning,[15] educational programs,[16] and development of career tools.[17] An assessment of the current needs of the national optics and photonics industry is crucially important due to the highly dynamic nature of photonics technologies, evolving geopolitical relations and supply chain considerations, and wider systemic changes in workplace dynamics brought about by the COVID-19 pandemic.

In this paper, an overview of existing Canadian photonics training programs is first presented; in particular, focus is provided on educational pathways for a Canadian student entering the photonics industry as a technician, scientist, or engineer. Findings related to current industry talent needs are then presented. The study is composed of two parallel and complementary investigations. The first investigation examines publicly accessible online job

Further author information: (Send correspondence to D.H.)
D.H.: E-mail: dhuta087@uottawa.ca

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postings related to optics and photonics from the first three months of the 2023 calendar year to identify common hiring requirements. Second, a nationwide survey was carried out, with distribution to over 300 organisations having significant activities in the Canadian optics and photonics ecosystem. By examining these two results together, we present a comprehensive portrait of the technical needs and hiring trends of the Canadian photonics industry.

2. EXISTING PHOTONICS TRAINING PROGRAMS

The Canadian photonics ecosystem benefits from a strong talent pipeline with numerous high-quality training programs centered at major universities and an increasing number of colleges.

Prominent examples of photonics training at the technician and technologist levels include Niagara College (ON),[18] Northern Alberta Institute of Tehcnology (AB),[19] CEGEP André-Laurendeau (QC),[20] and CEGEP de La Pocatière (QC),[21] which offer two- to three-year Photonics Engineering Technician diplomas. Graduates of these programs obtain highly relevant workforce competencies, such as the skills needed to build, install, test, and maintain optical equipment, with very positive hiring outcomes in the local industry. Undergraduate programs such as physics and electrical engineering provide students with the necessary breadth of knowledge to specialize in photonics technologies in more focused programs after graduation. Several Canadian universities offer specialized optics and photonics training at the bachelor level, such as Carleton University (ON) - Optical Systems and Sensors program, Algonquin College (ON) - Photonics and Laser Technology program, and École Polytechnique de Montréal (QC) - Photonics Engineering.

At the graduate level, photonics training is largely centered at the U15 Group of Canadian Research Universities, an association of 15 research-intensive universities across Canada. However, there are also significant graduate-level photonics research and training activities in non-U15 member research institutions, such as at l'Institut national de la recherche scientifique and the Royal Military College of Canada. Several training programs supported by the Collaborative Research and Training Experience (CREATE) program of the National Sciences and Engineering Research Council of Canada (NSERC) have demonstrated success in the training of new highly qualified personnel for the photonics industry. Funds from NSERC's CREATE program are typically used for supporting training at the graduate level, particularly in the form of graduate student stipends. However, several NSERC CREATE programs have evolved into standalone training workshops. A notable example is the highly successful Silicon Electronic Photonic Integrated Circuits (SiEPIC) training program, which offers participants a practical training experience in which they learn relevant theory before continuing to the design, tapeout, and characterization of a photonic integrated circuit.[22] Additional examples of standalone training programs include the internationally-offered edX "Silicon Photonics Design, Fabrication, and Data Analysis" course based out of the University of British Columbia.

3. EMPIRICAL STUDY

Publicly-accessible job postings were collected and analysed to gain insight on in-demand skills in the Canadian photonics industry. Online job postings typically include specific keyword requirements in the job descriptions, which can be representative of desired competencies. Collected job description data were processed to identify in-demand skills and clusters of related skills. Similar studies have been performed in the past for various industries, such as for the data science industry.[23] Our investigation is the first such study applied to the photonics industry.

3.1 Data Collection and Processing

The data collection and analysis processes are summarized in Figure 1. Two popular publicly-accessible job posting platforms, Indeed and LinkedIn, were used to collect job descriptions in the photonics industry. To automate the collection process, Python-language scripts, using Selenium WebDriver[24] and Beautiful Soup[25] library tools, were implemented to search and save posting data for jobs in Canada using "photonics" and "photonique" as the platform search terms. A total of 231 unique jobs were collected for this analysis, comprised of both English and French language job postings, spanning a collection period of 10 weeks. All French language postings were translated to English using deep-translator[26] in Python prior to further processing. The 231 job postings stemmed from 86 different companies across Canada; of these companies, 42 were located in Ontario, 29 in Quebec, 10 in British-Columbia, 1 in Nova-Scotia, 2 were fully remote and the remaining 2 preferred not to disclose geographical information inside Canada.

Natural language processing (NLP) techniques were applied to the collected data. The job descriptions were then trimmed to remove punctuation and "stopwords," common English words that do not provide interesting information, such as grammatical articles and conjunctions (e.g. "the" and "or"). An iterative refinement process was then conducted to update the stopword list to remove irrelevant but frequent terms, such as "insurance" and "vacation." Tokenization, stemming, and lemmatization were applied to consolidate different representations of identical notions (e.g. "R&D" and "research and development"). A frequency-based approach was then applied to extract the most common unigrams, such as "software," and bigrams, such as "silicon photonics." The resulting 50 most-frequently listed skills were validated against skills extracted from skillNER,[27] an open-source rule-based NLP module for skills and certifications extraction, and from the research group's experience in the photonics industry. The 50 most frequently listed skills are visualized in a wordcloud, provided for completeness as Figure 5 in Appendix A.

Hierarchical clustering was performed to group extracted skills using a distance matrix calculated from the co-occurrence of skills in the same posting based on the Unweighted Pair Group Mean Averaging method. In other words, skills that co-occur more frequently are more closely clustered. The clustering algorithm was implemented with SciPy,[28] and the methodology follows the data analysis framework used in a recent study conducted to identify skill clusters in job advertisements for Industry 4.0.[29] This type of co-occurrence analysis provides insight into which skill sets should be taught adjacently to better prepare students for the workforce.

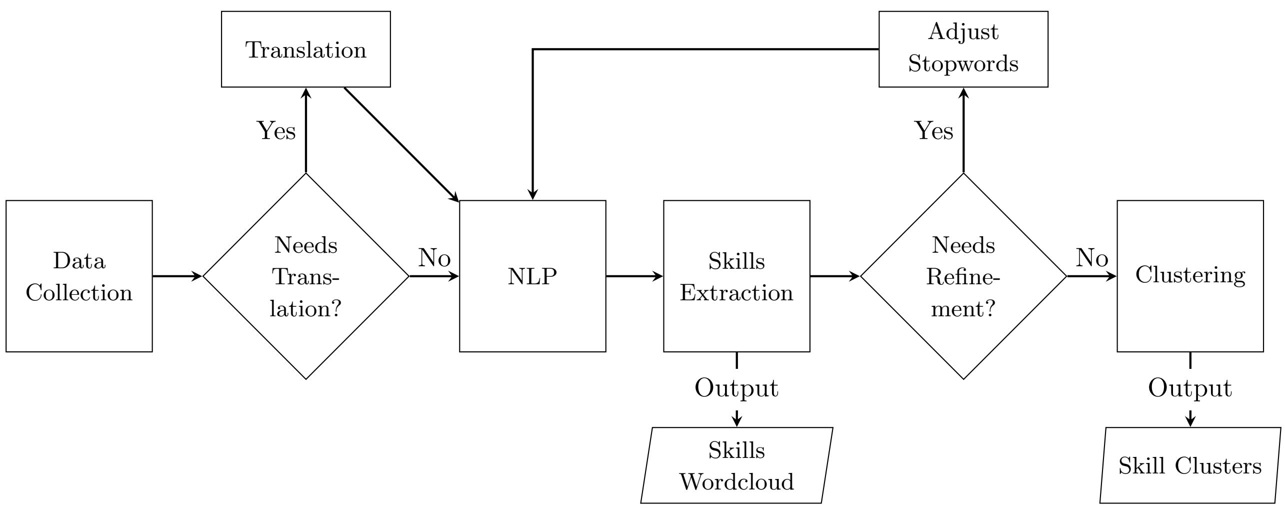


Figure 1: Data Collection and Analysis Process

Phrases relating to gender and orientation equality were highly prevalent across all job postings: as suggested by their prevalence, equity, diversity, and inclusion (EDI) concepts are critically important topics in the larger photonics workforce. For the purpose of this study, EDI-related terms were filtered out to better enable the identification of skills specific to technical roles.

3.2 Results and Interpretations

The identified skills are derived from photonics-related jobs, which includes various sub-disciplines such as dedicated software developers and technicians. Out of the 231 jobs collected, 114 are situated in Ontario, 73 in Québec, 35 in British Columbia, 1 in Nova Scotia, and 8 were either fully remote or unspecified. The following sub-sections describe the skills identified and their thematic clustering.

3.2.1 Skills Identification

Table 1 summarizes the top eight "soft" and "hard" skills found in 231 unique job postings in Canada. The most frequently desired attribute in almost every job posting is "Experience," an indicator of the industry's need for experienced personnel. Soft skills, such as "Communication Skills," "Teamwork", and "Leadership" are also shown to be prevalent and in high-demand across job postings. Various hard skills were also identified, such as "Silicon Photonics" and "Electrical Engineering", which appeared organically in the extraction process. "Design" and "Development" were heavily prevalent in most job postings. However, it is noted that the context surrounding these terms can be vague and be over-representative of the industry's demand for skills in design. Interestingly, "Software" skills are ranked higher than other photonics-related hard skills. "Quantum Technologies" were also found to be prevalent, ranking just below "Engineering Physics." "English" and "French" language skills were also found to be highly desirable, reflecting Canada's bilingualism.

Table 1: Top Skills in Job Postings Across Canada

Soft Skills	Hard Skills
Experience	Design & Development
Teamwork	Software
Communication Skills	Silicon Photonics
French English	Product Development
Problem Solving	Electrical Engineering
Management	Test Planning
Leadership	Engineering Physics
Project Management	Quantum Computing

The skills extraction process was also performed separately for the the provinces of Ontario, Québec, and British Columbia. Table 2 shows the top eight skills extracted from each province, merging soft and hard skills. The results suggest that different skill sets are demanded in different provinces. Ontario's demand for "Product Development," "Software," and "Test" skills seem more prevalent compared to other provinces. In British Columbia, the demand seems concentrated towards "Silicon Photonics" and "Quantum Technologies," with the 9^{th} top skill for British Columbia being "Spin Qubits." An interesting note is that "Experience" is listed less frequently in job postings in British Columbia relative to other provinces. This may be due to quantum 2.0 technologies being a very nascent field in which experience simply does not yet exist to the extent of other more mature optical technologies. The skills identified in Québec are "Design" and "Photonic Components," which is consistent with the nature of Québec's industry in providing components and sub-system products for varied application sectors.[30] It is also worth noting that "French [and] English" shows up as a top skill for Québec, which is a predominately francophone province in Canada. This requirement is less frequent in other provinces, which are predominately anglophone.

Table 2: Top 8 Skills in Job Postings by Province

Ontario (n=114)	Québec (n=73)	British Columbia (n=35)
Experience	Experience	Design
Design	Teamwork	Quantum Computing
Communication Skills	Engineering Physics	Quantum Technologies
Software	Communication Skills	Silicon Photonics
Product Development	Software	Teamwork
Teamwork	French English	Experience
Test Planning	Photonic Components	Electrical Engineering
Test Equipment	Design	Communication Skills

3.2.2 Skills Clustering

Table 3 shows the results of the hierarchical clustering process; these can be inferred by examining a dendrogram, provided for completeness as Figure 6 in Appendix A. The results show several clusters of correlated skills.

Table 3: Skill Clusters by Hierarchical Clustering

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Experience Teamwork Design Develop	Development Team Product Development Software Development	Production Equipment Software Technical	Quantum Technologies Quantum Computing	Focused Design Design Automation Integrated Photonics
Cluster 6	**Cluster 7**	**Cluster 8**	**Cluster 9**	**Distinct Skills**
Management Project Processes R&D Team Player Communication	Optics Photonics Photonic Components Fiber Optics Optical Systems	Lead Product Systems	Design Development Optical Components Project Management Test Equipement English French Computer Engineering Problem Solving Engineering Degree	Electrical Engineering Testing Planning Silicon Photonics Engineering Physics

Common themes can be found across several clusters. For example, clusters 4 and 7 show distinct categories of skills for "Quantum" and "Photonic" knowledge, respectively. Clusters 2 and 5 indicate an emphasis for "Software development" and "Design" skills. Cluster 6 largely encapsulates soft skills. Four of the most in-demand skills are grouped together in cluster 1 as these skills co-occur in almost every job posting. Cluster 9 contains other hard skills that are often described together in job postings. It is again interesting to note the inclusion of "English [and] French" in this skill category, hinting towards the combination of communication and technical skills important to the Québec photonics industry. Clusters 3 and 8 contain other hard skills that, while appearing together frequently, are more vague and difficult to label with a skills theme. Some skills, contained in the final "Distinct Skills" cell in the table above, were found to be highly in-demand, but are difficult to categorize with other skills.

4. SURVEY STUDY

A survey was designed to measure the requirements for the photonics industry in Canada for (a) knowledge and technical skills, namely design, manufacturing, testing, and software. Questions were also included to assess (b) hiring trends in the sector. The survey was distributed in April 2023 and open for responses over a 1-month period. Distribution strategies included mailing lists of regional and national photonics clusters (Optonique, Photons Canada) and special interests groups in photonics (CMC Microsystems, SiEPIC, McGill University Photonics Systems Group). The survey was promoted on social media platforms (Facebook, Twitter, LinkedIn), along with word-of-mouth invitations. The survey questions are provided in Appendix B for completeness.

A total of 87 responses within Canada were received within a survey period of 30 days, with 62 unique organizations identified; there are an estimated 400 photonics companies in Canada.[31] The demographics of respondents are divided as Technical Staff (n=25), Director (n=34), Supervisor (n=22), and a self-described "Other" category (n=6). There is a lack of diversity in the geographical demographics amongst respondents. The provincial breakdown of responses is as follows: Quebec (n=52), Ontario (n=23), British Columbia (n=6), Alberta (n=1), and (n=5) did not indicate a province. Further outreach is required for Western provinces and Ontario to capture a more representative portrait of the industry in future studies. This section summarises the results of the survey.

4.1 Skills and Knowledge Trends

The general knowledge portion of the survey aims to assess the importance of breadth of knowledge and soft skills. Knowledge of "Photonics" was the most important skill on average amongst respondents, supporting the methodology to determine skills in sub-fields of photonics across the Canadian industry. This is followed by "Oral Communication Skills" and "Written Communications Skills." Knowledge of "Electronics" and "Signal Processing" were determined to be the next most important technical elements. Undergraduate curricula in electronics provide a pipeline for students with relevant talent through the teaching of electric field fundamentals, electromagnetism, and photonics. To better prepare students in these programs for industry employment, the importance of oral and written communications skills should also be emphasized. "Leadership" and "Health, Safety and Ethics" were ranked next. "Quantum Photonics" was ranked bottom, which may be a result of the demographics of participants; indeed, based on the job search analysis, a larger representation of respondents in British Columbia might have elevated the importance of this category on the national scale.

Skill trends were divided into technical categories consisting of design, testing, manufacturing, and software. Respondents (n=87) were directed to the aforementioned sections via survey branching techniques if they indicated it was relevant to their field. The skills and corresponding index for each technical category are displayed in table 4. By comparing the responses across all technical categories, the 24 survey questions were ranked by mean scale of importance, as seen in Figure 2. The skills are clustered and ranked in order of importance as follows: data analysis (T3, T2, S1, M5), technical communication (T5), photonics systems techniques (T2, T4, M3, M4), generic design skills (D0-D4), specialized manufacturing techniques (M0-M2, M6) and all other types of software skills (S0, S2-S5).

The survey methodology does not provide significant insight into the causation or the correlation with other skills. Further studies involving interviews may be useful to precisely determine why participants associate a certain level importance to a given survey question. A summary plot of the relative importance of general skills and knowledge is provided for completeness in figure 7 in Appendix B.

Table 4: Skills and Index

Index	Design Skills
D0	Experience in component simulation software (Lumerical, COMSOL, SPICE, etc.)
D1	Experience in layout and verification software (EDA, Quartus, Layout, etc.)
D2	Experience of system design software (Synopsis, KLayout, Cadence, etc.)
D3	Experience in packaging and optomechanics software (Solidworks, Fusion360, etc.)
D4	Experience in design-for-testing and design-for-packaging
Index	Manufacturing Skills
M0	Experience in front-end wafer processes (lithography, wafer bonding, etc.)
M1	Experience in subtractive manufacturing (etching, polishing, dining, etc.)
M2	Experience in additive manufacturing (deposition, oxidation, implantation, metalization, etc.)
M3	Experience in optics packaging techniques (fiber gluing, lens installation and alignment)
M4	Experience in integrated packaging techniques (die bonding, flip-chip bonding, etc.)
M5	Experience in quality and reliability
M6	Experience in glass/lens manufacturing processes
Index	Testing Skills
T0	Experience using imaging equipment
T1	Experience installing optical equipment for a new experiment
T2	Experience characterizing optical/photonic experiments
T3	Experience analyzing data (Python, Matlab, Excel, etc.)
T4	Experience in test tools automation
T5	Experience writing scientific reports
Index	Software Skills
S0	Experience in user experience (UX) software
S1	Experience of data analytics (Python, Matlab, Excel, etc.)
S2	Experience in AI or machine learning
S3	Experience in object-oriented programming
S4	Experience in hardware description language (Verilog, VHDL, etc.)
S5	Experience managing databases (SQL)

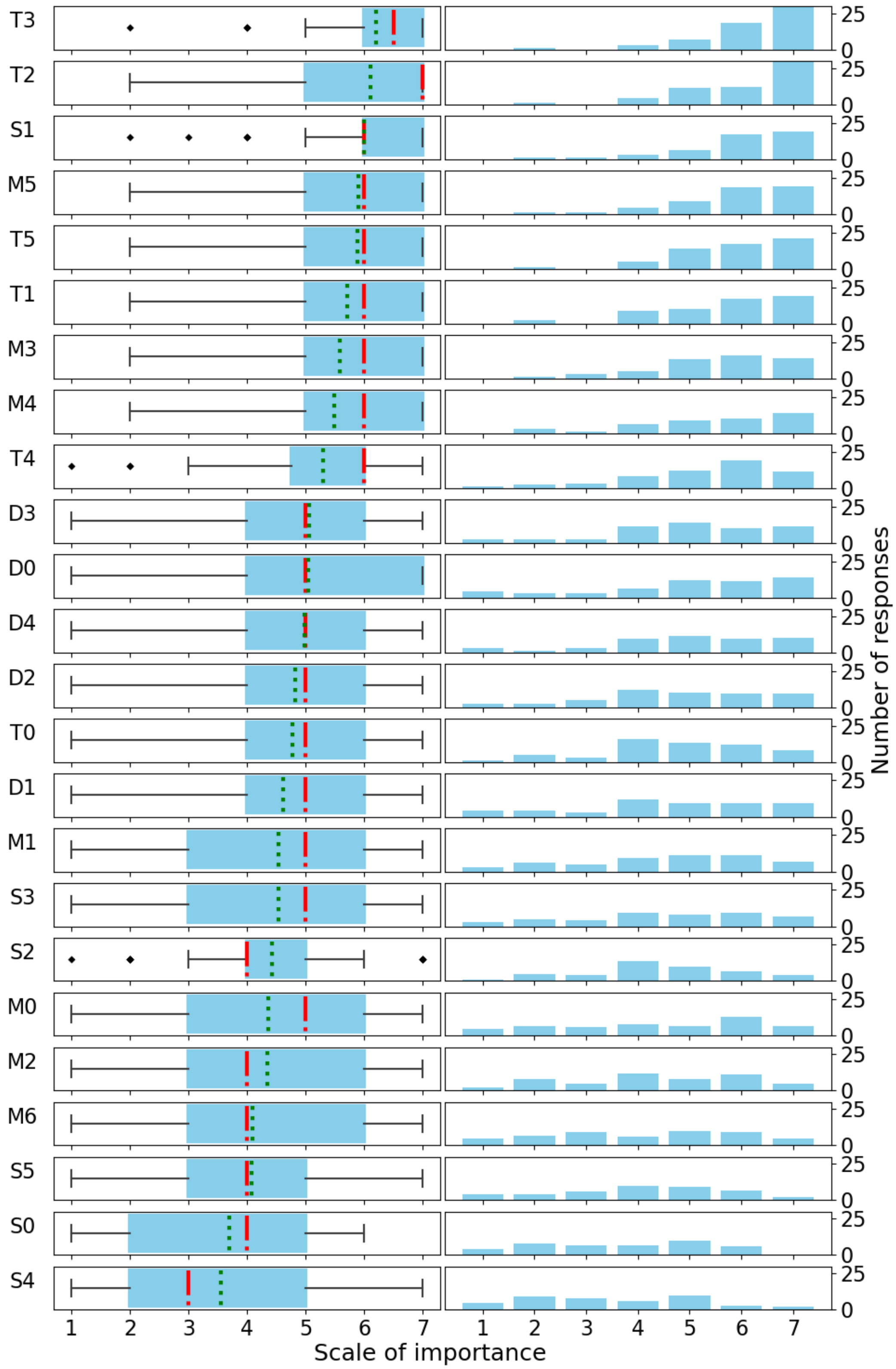
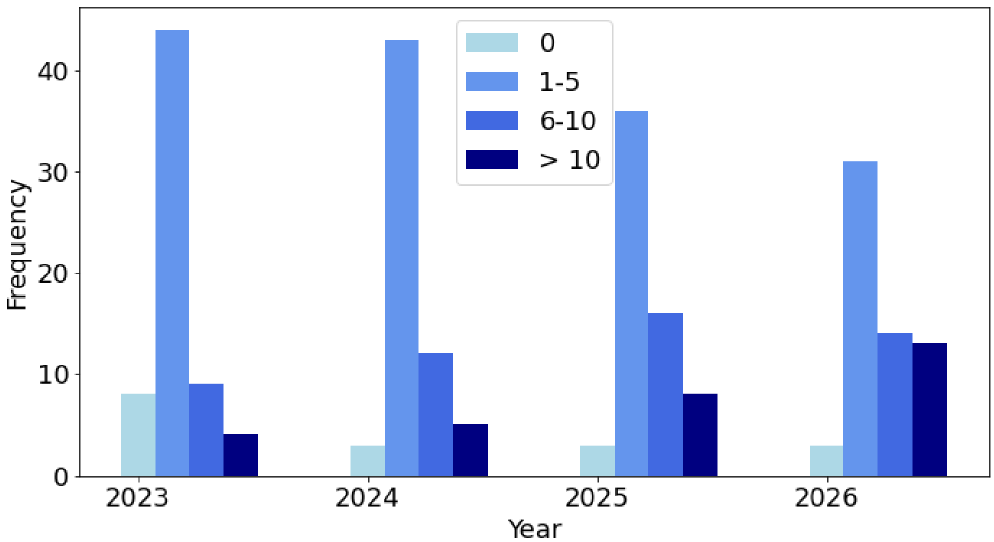


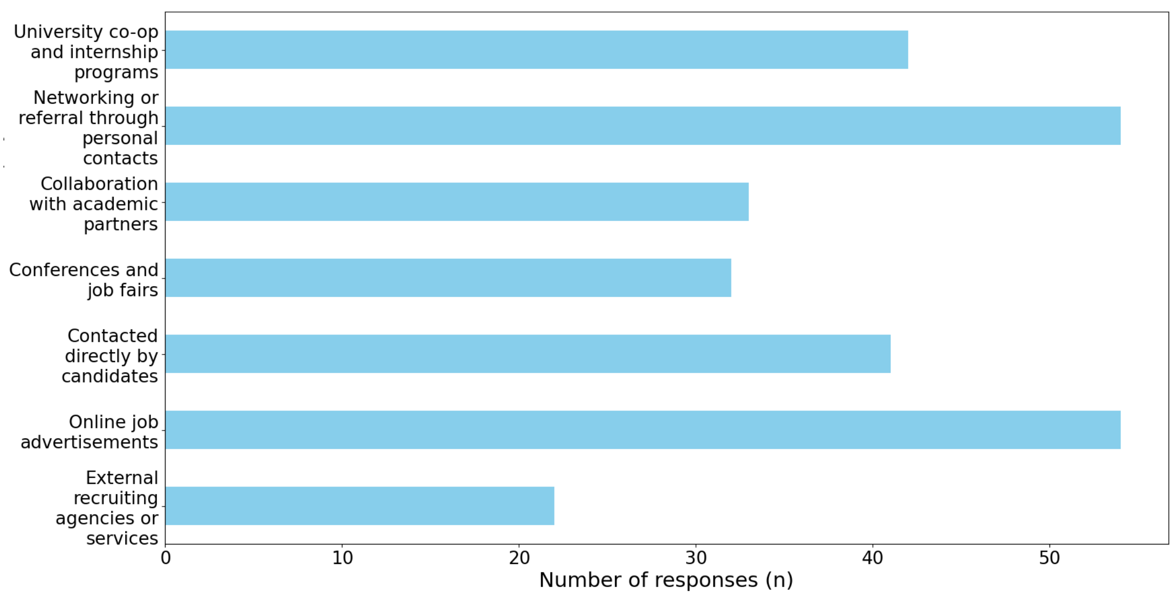
Figure 2: Box plot and histogram of all survey skills ranked by importance. Vertical red lines indicate the median and vertical green lines indicate mean. The scale of importance using a 7-grade Likert scale with rankings of 1 ("Not at all important"), 4 ("Neutral") and 7 ("Very important").

4.2 Hiring Trends

Respondents were asked to provide estimates for the number of new hires in their management groups, i.e. direct reports, rather than for the overall size of the organization. This permitted for multiple individuals in different technology areas within an organization to provide responses. Figure 3a highlights that most line managers predict a steady hiring count of one to five employees per year over the next three years and anticipate faster growth afterwards. Respondents were asked which methods have been successful for recruiting new employees; these are summarized in figure 3b. "Online Job Adverts" and "Networking or referrals" are the most common hiring resources used, which is consistent with trends observed in global surveys of individuals in the industry.[32] "Internships, co-op and collaboration with academic partners" provide a significant route for employers to find new talent, which is a trend not found in global reports.[32] "Recruiting agencies," and "Conferences and job fairs" are also noted as important resources used by employers.



(a) Figure 3a: bar graph of respondents' expected hiring trends.



(b) Figure 3b: bar graph of respondents' hiring resources used.

Respondents were asked to report the level of difficulty they experienced in hiring for five types of job functions. The greatest difficulties are measured for technical roles in design (H0), software (H3), manufacturing (H1) and testing (H2) in decreasing order of difficulty. Business development roles (H4), and project, programs and product management (H5) had the lowest mean and median for hiring difficulty. Insight provided by responses to the open prompt “Share common hiring challenges that you face to find new employees” indicate that a lack of experience (n=13), high competition (n=7), and a lack of qualified candidates (n=5) as the main challenges. This correlates with the need for “Experience” found as part of the skills identification in the empirical study. Figure 4 summarizes the challenges for hiring managers.

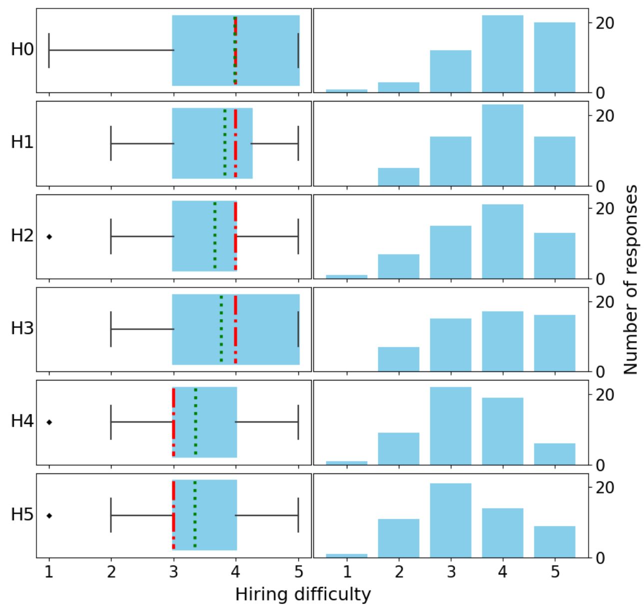


Figure 4: Box plot and histogram of hiring difficulties survey responses. The indexes are “Design” (H0), “Manufacturing” (H1), “Testing” (H2), “Software” (H3), “Business Development” (H4), and “Project, Programs and Product management” (H5).

5. DISCUSSION AND PERSPECTIVES

The intent of this work was to provide a snapshot of skills desired in the Canadian photonics industry building on previous international efforts, and in the context of the Canadian education and training ecosystem. An empirical study based on the analysis of public job postings identified in-demand soft and hard skills in the Canadian industry. The most demanded soft skills, such as communication skills and teamwork, were as deemed as valuable as in-demand technical skills. Clusters of skills were also identified, which include areas for technical communication, photonics systems, software, quantum technologies, and design. Skills were found to vary by province, indicative of different levels of demand and specialization for different geographic regions.

A survey of directors, supervisors and technical personnel identified specific skills that have a high degree of importance within the photonics industry. These are, in decreasing order of importance, data analysis, technical communication, photonics systems packaging and characterization, design, and specialized manufacturing techniques. The importance of data analysis skills correspond to the importance indicated by the empirical study. The survey lacks geographical diversity amongst respondents, with a non-representative distribution of responses compared to the industry location and size. Further efforts are required to obtain a more representative census of the Canadian photonics ecosystem at large. A case study using data obtained by the Québec photonics industry - which includes 52 survey responses from 46 companies, and 72 job postings from 29 companies - may be beneficial for highlighting the value of future initiatives. Recent studies justify the need for more in depth qualitative analysis.[11, 14]

The findings from both the empirical and survey study use a skills-based approach, rather than a jobs-based approach; further analysis of the job titles of survey respondents may offer insight into the types of jobs in demand and the adequacy of the training system in providing a pipeline of skilled trainees for the workforce. Quantifying this demand may have important repercussions on training programs; for instance, by extrapolating results from the first three months of 2023, the annual demand for technologists in Québec alone, representing half of the Canadian industry,[30, 31] would be greater than the current annual intake for Canada-wide technologist training programs[18, 20, 21] based on informational conversations with the respective program directors.

It is expected that a specific job role will encompass a given set of skills; equally, specific skills can provide competencies for many job roles. Pertinent experiential learning in training centres and via upskilling & reskilling of the workforce may be desirable based on the measured prevalence of the "Experience" requirement. Future studies will be needed to map the output of academic programs to effectively link them to the methods described herein to assess the photonics industry's requirements.

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[32] "Global Optics and Photonics Salary Report 2023," tech. rep., SPIE, Bellingham, WA (2022).

7. APPENDIX A - SUPPLEMENTAL MATERIAL "EMPIRICAL STUDY"

Publicly-accessible job postings were collected and analysed to gain insight on in-demand skills in the Canadian photonics industry. Online job postings typically include specific keyword requirements in the job descriptions, which can be representative of desired competencies. Collected job description data were processed to identify in-demand skills and clusters of related skills. The most frequent unigrams and bigrams are visualized as a wordcloud, with text sizes representing the frequency of the terms as illustrated in Figure 5.

Figure 5: Wordcloud of most the frequently mentioned skills desired in publicly available online job postings in early 2023.

Data collection and clustering have been performed for job postings in the past for various industries, such as for the data science industry. The dendrogram tree-structure shown in Figure 6. the relationship between skills with lines that link related skills, determined by the skills' proximity to other skills. The top of the tree encompasses all skills, and branches downward into distinct clusters.

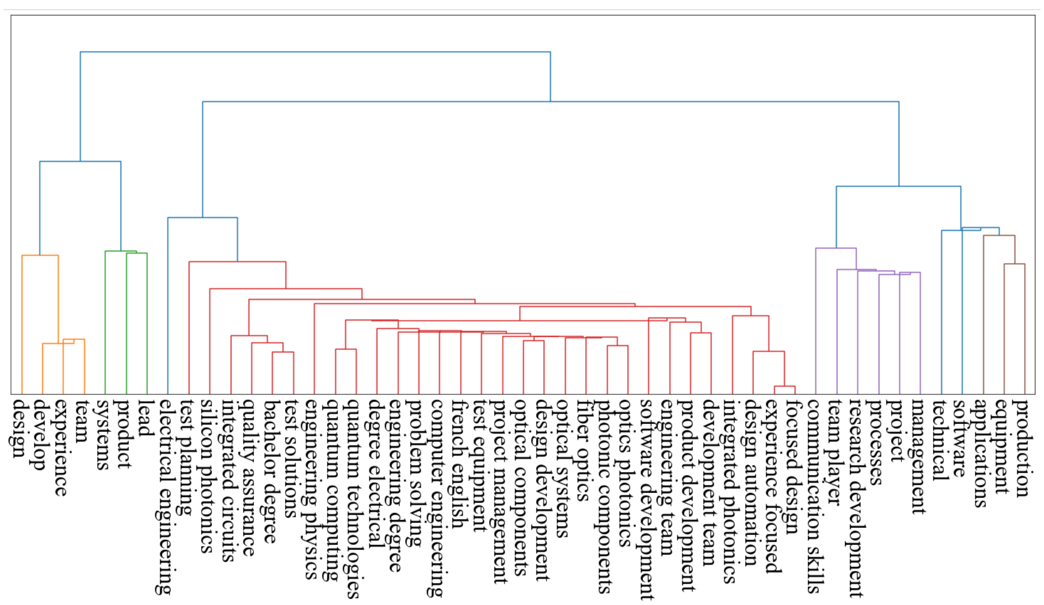

Figure 6: Dendrogram showing results of clustering of skills.

8. APPENDIX B - SUPPLEMENTAL MATERIAL "SURVEY STUDY"

The survey questions are provided in this appendix. For multiple-choice questions listed as 'Qx', a set of corresponding answers is provided in 'Qx.Ay'. The survey was available in two languages, French and English, with all translations done via DeepL Translator. For ease of reading, only the English version is presented.

- Q1: Please select your language
  - Q1.A1: English
  - Q1.A2: Français
- SECTION 1: DEMOGRAPHICS
- Q3: Organization type
  - Q3.A1: Industry
  - Q3.A2: Academia
  - Q3.A3: Non-profit
  - Q3.A4: Government
  - Q3.A5: Other:
- Q4: Organization Name:
- Q5: Country:
- Q6: Province
- Q7: City:
- Q8: Job role
  - Q8.A1: Supervisor / Manager
  - Q8.A2: Director
  - Q8.A3: Scientist / Engineer / Technician
  - Q8.A4: Other:
- Q9: Please provide consent for the information you provide to be shared confidentially between project partners and used for statistical purposes. (Note: This consent will not affect your participation in this survey and is voluntary.)
- Q10: Please provide an email address to receive early access to the survey results:
- SECTION 2: KNOWLEDGE AND SKILLS
- Q11: Please indicate how important you think the following skills are in hiring:
  - Q11.A1: Knowledge of photonics
  - Q11.A2: Knowledge of electronics
  - Q11.A3: Knowledge of optical signal processing
  - Q11.A4: Knowledge of electronic signal processing
  - Q11.A5: Knowledge of quantum photonics
  - Q11.A6: Knowledge of health, safety and ethics
  - Q11.A7: Leadership Experience
  - Q11.A8: Oral communication skills
  - Q11.A9: Written communication skills (includes writing emails, creating presentations and reports on technical data)

- Q13: If relevant to your hiring needs, please indicate how difficult it is to find trained talent in the following functions: (you will be asked to provide some details about skills needed in the next section)
  - Q13.A1: Design
  - Q13.A2: Manufacturing
  - Q13.A3: Testing
  - Q13.A4: Software
  - Q13.A5: Business development
  - Q13.A6: Project, program, and product management
  - Q13.A7: Other (please indicate below)
- Q14: If you selected "Other" above, please indicate functions where it's hard to find trained talent:
- Q16: DESIGN. This section is intended to determine proficiencies required to conduct photonic design. Please indicate how important experience is for the following items (leave blank if you do not know).
  - Q16.A1: Experience of component simulation software (for e.g. Lumerical, COMSOL, SPICE, etc.)
  - Q16.A2: Experience of layout and verification software (for e.g. EDA, Quartus, Layout etc.)
  - Q16.A3: Experience of system design software (for e.g. Synopsys, KLayout, Cadence, etc.)
  - Q16.A4: Experience of packaging and optomechanics software (for e.g. Solidworks, etc.)
  - Q16.A5: Experience in design-for-testing and design-for-packaging.
- Q17: Are there particular tools that are essential to have experience in?
- Q18: Is there any other subject that you believe experience would be needed in? If so, please rate 1-7.
- Q20: MANUFACTURING. This section is intended to determine proficiencies required to conduct photonic fabrication and packaging.Please indicate how important experience is for the following items (leave blank if you do not know).
  - Q20.A1: Experience in semiconductor front-end wafer processes (lithography, wafer bonding, etc.)
  - Q20.A2: Experience in subtractive manufacturing (etching, polishing, dicing, etc.)
  - Q20.A3: Experience in additive manufacturing (deposition, oxidation, implantation, metallization, etc.)
  - Q20.A4: Experience in optics packaging techniques (fiber gluing/lens alignment and attach)
  - Q20.A5: Experience in integrated packaging techniques (hybrid/heterogenous integration techniques: die bonding, flip-chip bonding, wirebonding, pick-and-place, etc.)
  - Q20.A6: Experience in quality and reliability
  - Q20.A7: Experience in glass/lens manufacturing processes
- Q21: Is there any other subject that you believe experience would be needed in? If so, please rate 1-7.

- Q23: TESTING. This section is intended to determine proficiencies required to conduct photonic testing. Please indicate how important experience is for the following items (leave blank if you do not know).
  - Q23.A1: Experience using imaging equipment (including scanning electron microscope, atomic force microscope, optical microscopes, etc.)
  - Q23.A2: Experience and installing optical equipment for a new experiment
  - Q23.A3: Experience characterizing optical/photonic experiments (includes experience for measurements using generic optical equipment including power meter, optical spectrum analyzers, etc.)
  - Q23.A4: Experience analyzing Data (Matlab, Python, Excel, etc.)
  - Q23.A5: Experience in test automation tools (LabVIEW, etc.)
  - Q23.A6: Experience writing scientific reports and or summary of the experiment
- Q24: Is there any other subject that you believe experience would be needed in? If so, please rate 1-7.
- Q26: SOFTWARE This section is intended to determine proficiencies required for software applications. Please indicate how important experience is for the following items (leave blank if you do not know).
  - Q26.A1: Experience in user experience (UX) software?
  - Q26.A2: Experience of data analytics (Python, Matlab, Excel etc.)?
  - Q26.A3: Experience of AI or Machine Learning?
  - Q26.A4: Experience in object oriented programming?
  - Q26.A5: Experience in hardware description language (Verilog, VHDL, etc.)
  - Q26.A6: Experience managing databases (SQL)?
- Q27: Is there any other subject that you believe experience would be needed in? If so, please rate 1-7.
- SECTION 3: HIRING TRENDS
- Q29: How many people do you supervise?
- Q30: How many technical employees do you expect your group to hire in Canada in the indicated years (2023-2026)?
- Q31.A1: How many of your annual headcount are students, co-ops, or interns?
- Q31.A2: How many of your annual headcount are short-term, or contract workers?
- Q32: What resources do you use to find qualified candidates?
  - Q32.A1: External recruiting agencies or services
  - Q32.A2: Online job advertisements
  - Q32.A3: Contacted directly by candidates
  - Q32.A4: Conferences and job fairs
  - Q32.A5: Collaboration with academic partners
  - Q32.A6: Networking or referral through personal contacts
  - Q32.A7: University co-op and internship programs
  - Q32.A8: Other, please describe:
- Q33: Share common hiring challenges that you face to find new employees:
- Q34: Share successful methods that you have used to recruit new employees:
- Q37: Does your organization support training and professional development of skills to employees?
- Q38: If yes, what is the approximate annual budget per employee including costs of certifications, equipment rentals and material costs? This question excludes employee salary.

With reference to the tabulated items above, the results for survey questions on knowledge (Q11), design (Q16), manufacturing (Q20), testing (Q23), and software (Q26) are provided for completeness. Each figure describing survey responses includes a box and whisker plot and a histogram side-by-side. The left column of each figure contains a box and whisker plot, more commonly known as a box plot, it has seven pieces of information: the minimum, first quartile, median, mean, third quartile, maximum and fliers. The skyblue colored box denotes the interquartile range (IQR), which is the range between the 25th and 75th percentile of responses. A vertical red within the IQR box indicates the median and a green line for the mean. As for the whiskers, they extend to the smallest or largest data point from their respective quartiles to 1.5 times the IQR. Responses which were outside the boundaries of the whiskers are known as fliers, fliers denote outliers in the data set that are more than 1.5 times the IQR from the first and third quartiles. Comparatively, the histogram provides the number responses relative to their scale of importance. The scale of importance ranges from 1 to 7. With 1 being the least important and 7 being the most important. The data analysis and visualization were conducted using Numpy (histograms), Pandas and Seaborn (box plots) Python libraries.

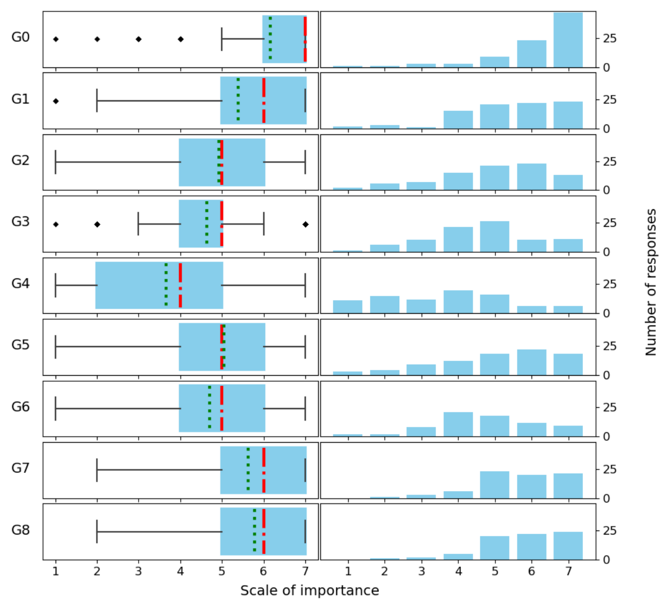

Figure 7: Box plot and histogram of general skills and knowledge survey responses.

Table 5: General skills and knowledge question index

Index	Survey Question
G0	Knowledge of photonics
G1	Knowledge of electronics
G2	Knowledge of optical signal processing
G3	Knowledge of electronic signal processing
G4	Knowledge of quantum photonics
G5	Knowledge of health, safety and ethics
G6	Leadership experience
G7	Oral communication skills
G8	Written communication skills

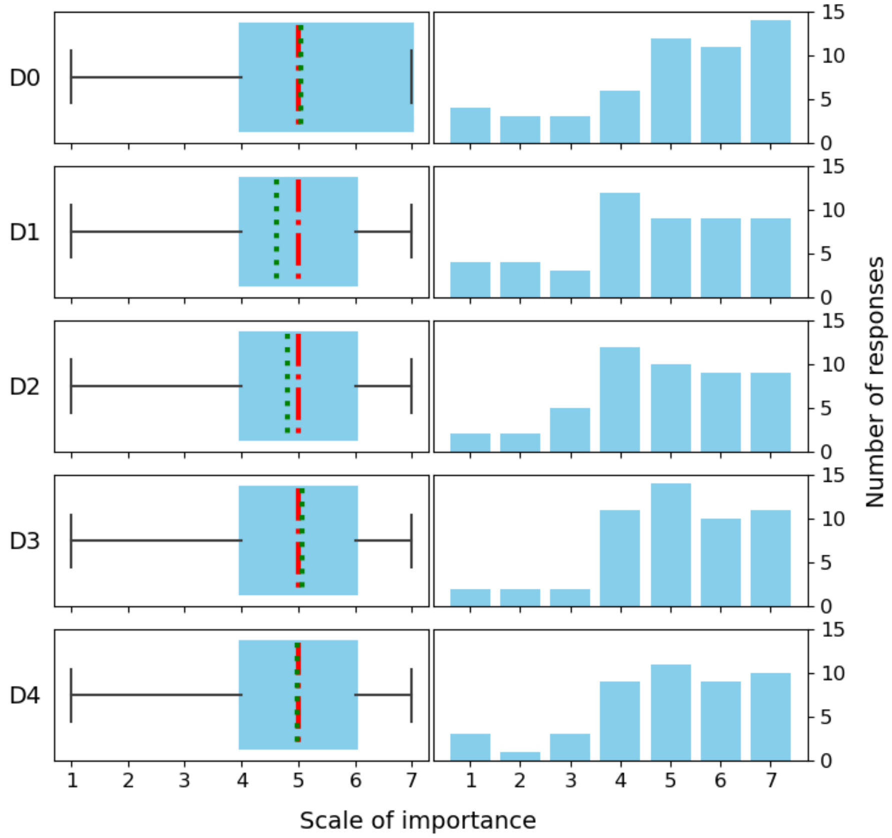

Figure 8: Box plot and histogram of design skills survey responses

Table 6: Design skills and index

Index	Design Skills
D0	Experience in component simulation software (Lumerical, COMSOL, SPICE, etc.)
D1	Experience in layout and verification software (EDA, Quartus, Layout, etc.)
D2	Experience of system design software (Synopsis, KLayout, Cadence, etc.)
D3	Experience in packaging and optomechanics software (Solidworks, Fusion360, etc.)
D4	Experience in design-for-testing and design-for-packaging

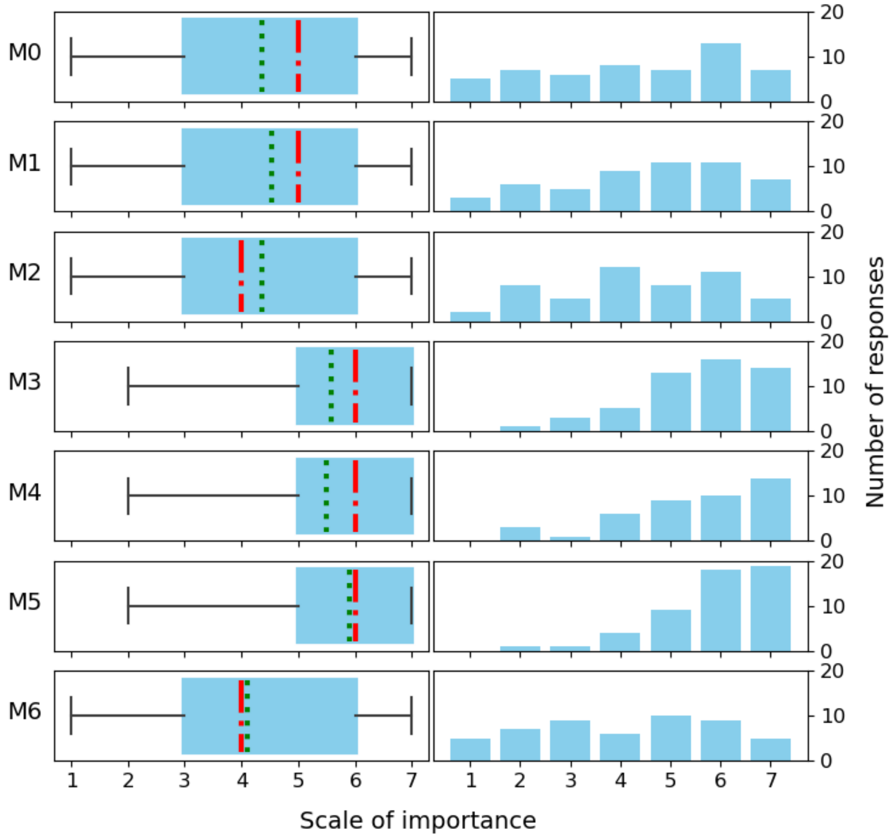

Figure 9: Box plot and histogram of manufacturing skills survey responses.

Table 7: Manufacturing skills question index

Index	Manufacturing Skills
M0	Experience in front-end wafer processes (lithography, wafer bonding, etc.)
M1	Experience in subtractive manufacturing (etching, polishing, dining, etc.)
M2	Experience in additive manufacturing (deposition, oxidation, implantation, metalization, etc.)
M3	Experience in optics packaging techniques (fiber gluing, lens installation and alignment)
M4	Experience in integrated packaging techniques (die bonding, flip-chip bonding, etc.)
M5	Experience in quality and reliability
M6	Experience in glass/lens manufacturing processes

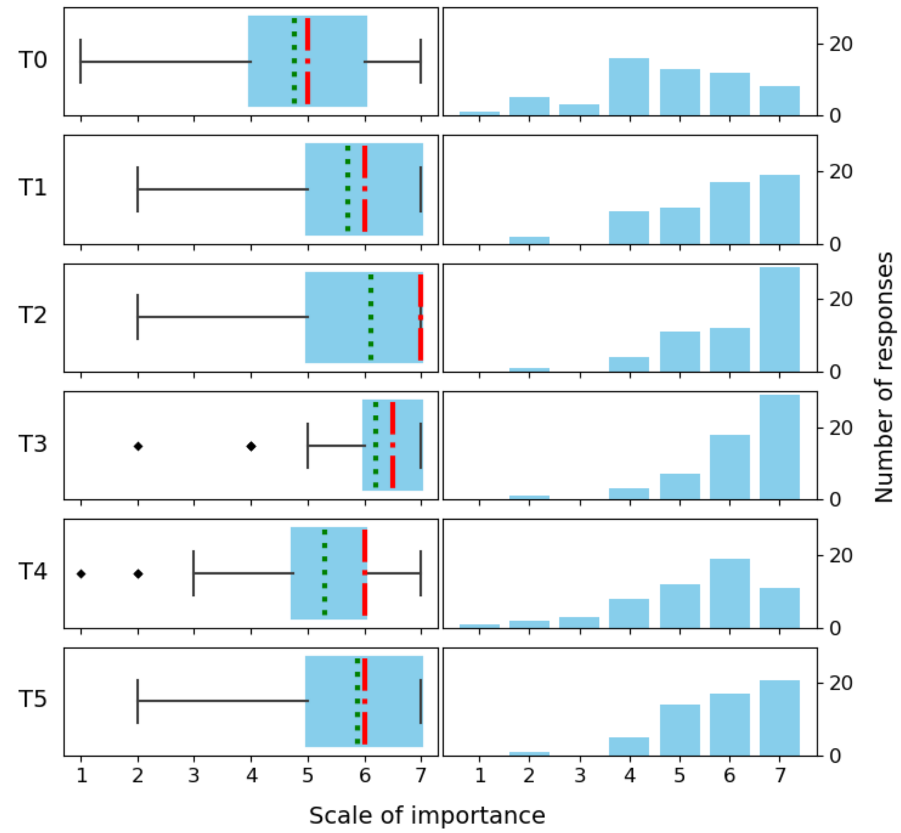

Figure 10: Box plot and histogram of testing skills survey responses.

Table 8: Testing skills question index

Index	Testing Skills
T0	Experience using imaging equipment
T1	Experience installing optical equipment for a new experiment
T2	Experience characterizing optical/photonic experiments
T3	Experience analyzing data (Python, Matlab, Excel, etc.)
T4	Experience in test tools automation
T5	Experience writing scientific reports

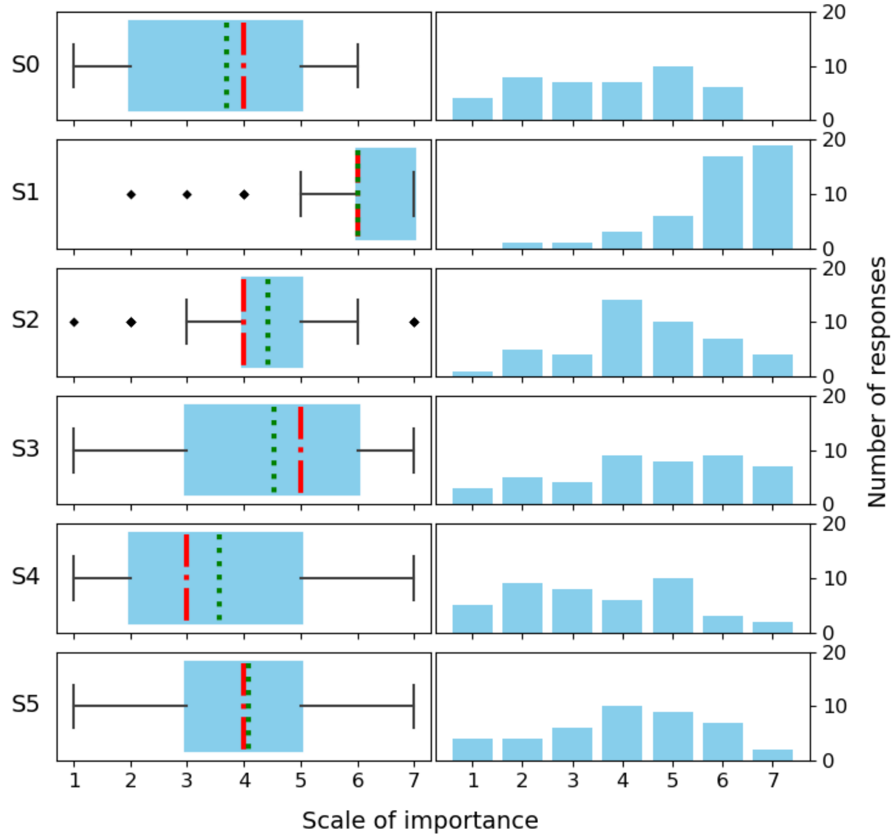

Figure 11: Box plot and histogram of software skills survey responses.

Table 9: Software skills question index

Index	Software Skills
S0	Experience in user experience (UX) software
S1	Experience of data analytics (Python, Matlab, Excel, etc.)
S2	Experience in AI or machine learning
S3	Experience in object oriented programming
S4	Experience in hardware description language (Verilog, VHDL, etc.)
S5	Experience managing databases (SQL)