# A Survey on the Need for Airborne Lidar Training

**Chris Hopkinson, Sorin Popescu, Martin Flood, and Robert Maher**

## Abstract
*Two questionnaires were sent out to over 600 members of the international lidar academic research and commercial mapping community, and a lidar research and training workshop was hosted in Halifax, Canada. The purpose of the questionnaires and the workshop was to better understand the status of, and needs for training within the lidar community. The results demonstrate that there is a clear need for training within both the end user and service provider sectors of the professional lidar community. It is speculated that although specific training needs differ, in terms of volume the end user community's need is at least an order of magnitude greater than in the service provider sector. Regarding training priorities, there appears to be some clear stratification between the needs of end users and service providers. In general, practical experience and "hands on" training methods were considered more useful for those entering into lidar related employment, but this perception was not shared by academics. Also, results indicated that "end user applications" were the priority topic in the end user academic and government communities, while in the lidar industry, training priorities were related to more technical and operational topics such as "data processing" and "project management." Within the lidar project workflow, six areas of responsibility were identified within the end user and service provider sectors (service provider operators, data processors, and project managers; and end user clients, project managers, and data processors), each of which having different training needs. The results of this study are being used by the Applied Geomatics Research Group to develop a suite of lidar training curricula from workshop seminars to industry-sponsored project-based internship programs.*

## Introduction
During recent years, airborne laser scanning or lidar (light detection and ranging) has increasingly been demonstrated as a highly efficient method of data collection for a variety of high-resolution topographic (Flood and Gutelius, 1997), forest (Lim *et al.*, 2003), wetland (Töyra *et al.*, 2003), snowpack (Hopkinson *et al.*, 2004), coastal (Webster *et al.*, 2004), and other mapping applications. Consequently, the lidar mapping industry has grown to over 110 commercial sensors worldwide and is predicted to continue growing by approximately 15 percent per annum to over 190 sensors by 2010 (TMSI, 2005). However, the technology and manipulation of the data is still treated with caution, and even considered somewhat esoteric by many potential users. There is generally a low awareness of the applications and benefits of the technology, and potential users of lidar data often cannot differentiate the merits between lidar and competing technologies, such as IFSAR and traditional stereo photogrammetry (TMSI, 2005). There are several reasons why relatively new technologies are treated with caution, and in the case of lidar mapping, the potentially high costs and huge volumes of data involved, and significant investment in time required by the end user to derive the information required are certainly major factors. Another factor is the generally low profile of lidar technology and applications in mainstream mapping, remote sensing, and geomatics curriculum. The objective of this paper is to investigate the training needs for lidar technicians and professionals in both the service provision industry and the end user communities with the ultimate aim of using this information to develop appropriate training curricula to meet these needs. The specific questions discussed are:

1. What training is currently available?
2. Who needs lidar training?
3. What needs to be trained?
4. What format should training take?

## Methods
Three primary data sources were used in conducting this study: results from two questionnaire distributions and a discussion forum hosted at the 1st Canadian Lidar Applied Research and Training (CLART) Workshop in Halifax, February 2005. Both questionnaires contained preliminary questions relating to the respondent's personal profile, and respondents were allowed to provide comments on any topics throughout the questionnaires. The first questionnaire was distributed in mid-2004, and the preliminary results presented at a special lidar session during the annual meeting of the American Society for Photogrammetry and Remote Sensing (ASPRS) in Denver (Popescu and Flood, unpublished

Chris Hopkinson and Robert Mayer are with Applied Geomatics Research Group, NSCC Annapolis Valley Campus, 50 Elliot Rd. Lawrencetown, NS BOS 1M0, Canada. C. Hopkinson is a member of the ASPRS Lidar Committee (chris.hopkinson@nscc.ca)

Sorin Popescu is with the Department of Forest Science, Texas A&M University, 1500 Research Plaza, Suite B223, College Station, TX 77845.

Martin Flood is with NIIRS10 (Canada), 57 Queen St. North, # 1111 Kitchener, ON N2H 6T7, Canada, and a member of the ASPRS Lidar Committee.

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data, 2004). The ASPRS questionnaire was distributed to approximately 360 people with connections to the lidar community: the ASPRS lidar committee, members of the International lidar Mapping Forum (ILMF), various government agencies, university faculty, and private remote sensing companies.

Most of the questions in the ASPRS questionnaire were binary and required yes/no (or "don't know/maybe/not applicable") style answers. The questions were primarily aimed at assessing the perceptions of potential supervisors of employees and students that might be expected to conduct lidar-related activities. The questions chosen for analysis in this paper were:

1. Are you currently investigating a practical application of lidar?
2. Do you see a shortage of employees with lidar experience?
3. Are you aware of any currently offered higher education course dedicated to or including lidar topics?
4. Would you consider hiring graduates with lidar courses on their transcripts?
5. Do you see lidar education/experience as an advantage for prospective remote sensing employees/graduates?
6. Which do you think is more important in hiring a staff member/graduate student for your lidar team: academic training or practical experience?
7. Rank the following topics in lidar, in order of perceived importance: (a) laser theory; (b) types of lidar sensors; (c) lidar processing algorithms; (d) lidar applications; (e) lidar versus radar and photogrammetry; (f) GPS (global positioning system) and INS (inertial navigation system) theory.

The Applied Geomatics Research Group (AGRG) compiled a second questionnaire in an effort to gather data for lidar curriculum development purposes. The AGRG questionnaire was distributed in February 2005 to approximately 550 people within the lidar community: International Society for Photogrammetry and Remote Sensing (ISPRS) lidar working groups, ASPRS Lidar Committee, Canadian Remote Sensing Society (CRSS) members, and participants of the CLART Workshop.

Where appropriate, respondents to the AGRG questionnaire were requested to rank their highest three responses (highest rank = 3 points, second = 2 points, third = 1 point) to assess the importance they attributed to particular issues. These questions were aimed at learning more about the training needs of both the professional lidar industry and end user community:

1. How many years have you been actively involved with lidar: (a) 0; (b) 0–1; (c) 1–5; (d) 5–10; (e) 10+?
2. Is it difficult to find candidates with lidar experience to fill lidar related positions in your profession?
3. Do you believe there is a need for independent lidar training?
4. Are you aware of any lidar training that was offered in the past or is currently available?
5. Do you conduct your own lidar training?
6. If YES to (4 or 5), what is the format of the training: (a) academic lidar program, (b) lidar component in academic program; (c) service provider training; (d) manufacturer training; (e) independent training program; (f) conference seminars and workshops?
7. Who do you think most needs or would be the biggest user of lidar training: (a) University researchers and students; (b) Government researchers; (c) Commercial service providers; (d) Commercial end-users?
8. What do you think should be the priority topics for a lidar training program: (a) Principles of lidar; (b) Mission planning and project management; (c) Field operations; (d) lidar data processing and calibration; (e) End-user applications; (f) Sensor fusion?
9. In your opinion, which is more important when designing a lidar training program: (a) Maximizing theoretical content; (b) Maximizing practical *hands on* opportunities; (c) Maximizing opportunities for attendance; (d) Minimizing participant costs?
10. What do you think is an appropriate entry qualification for a lidar training program: (a) No qualification; (b) High school diploma; (c) Relevant industry experience; (d) Relevant post secondary diploma; (e) Bachelors degree?
11. Based on your opinion of the needs for lidar training what do you think would be an appropriate duration: (a) Half a day or less; (b) One day; (c) One day to one week; (d) One week to one month; (e) A single term or semester; (f) One year; (g) Greater than one year?
12. Based on your opinion of the needs for lidar training, what do you think would be the most appropriate format: (a) Customized training at site of client; (b) "Boiler plate" (fixed curriculum) training at site of training institution; (c) Degree program; (d) lidar course within an academic degree program; (e) Vocational diploma/advanced diploma training?

The third primary data source available for this investigation was a discussion forum on lidar training hosted at the CLART workshop. Workshop participants were invited from the same distribution lists for the AGRG questionnaire, plus specific invitations were extended to members of the local geomatics community in eastern Canada. There were several objectives to the workshop but of relevance to this study were discussions focused on the four main questions posed in the introduction. Detailed notes were recorded throughout these discussions.

In total, over 700 people were invited to participate in the questionnaire and workshop efforts in an attempt to identify what, if any, lidar training needs exist, who needs the training and how it can most efficiently be delivered.

## Results

Of the 360 and 550 ASPRS and AGRG questionnaires distributed, there were 31 (9 percent) and 71 (13 percent) responses to each, respectively. Of these 102 responses, seven were from duplicate respondents. Of the 48 workshop attendees, 20 responded to either one or both of the questionnaires. In total, 128 individuals were able to express their opinions on lidar training needs either through the questionnaires or the workshop. Of these, over 80 percent were from North America (USA or Canada) and most of the remaining participants were from Europe. Clearly, there is some bias in the observations towards the North American experience; this partially reflects the geography of the authors of this study and subsequent distribution of questionnaires, but is also somewhat influenced by the substantially higher level of professional lidar community activity in North America relative to the rest of the world (see TMSI, 2005). In all three samples, the relative distributions of academic (faculty and students), government and industry responses were similar with approximately 45 percent, 16 percent, and 39 percent, respectively. See Table 1 for a summary of the participant profiles.

### ASPRS Questionnaire

The responses to binary "yes/no" type answers in the ASPRS questionnaire are summarised in Figure 1. To ensure that only those respondents expressing a definite opinion on the question were considered, all responses of "maybe," "don't know," or "not applicable" have been considered neutral and are not included in this summary. Questions 2, 4, and 5 ("shortage of experienced employees," "consider hiring lidar graduates," and "experience an advantage"), received strongly affirmative responses from all respondents expressing an opinion on the subject. This clearly suggests that while lidar experience and education are definite assets to those entering the lidar industry or undertaking lidar research, there are relatively few available people who

Table 1. Questionnaire and Workshop Participant Profiles. Note "Active Practitioner" is Defined Differently for Each Participant Category: ASPRS Questionnaire Must Have Answered Yes to Question 1; AGRG Questionnaire Did Not Answer "a" to Question 1; Workshop Participants Indicated Their Level of Lidar Activity at the Meeting

| Participant Profile | ASPRS Questionnaire | AGRG Questionnaire | Workshop |
|---|---|---|---|
| Number | 31 | 71 | 48 |
| North American | 26 (84%) | 52 (73%) | 47 (98%) |
| European | 5 (16%) | 14 (20%) | 1 (2%) |
| Rest of World | 0 | 5 (7%) | 0 |
| Academic | 13 (42%) | 36 (51%) | 19 (39%) |
| Government | 5 (16%) | 10 (14%) | 9 (19%) |
| Industry | 13 (42%) | 25 (35%) | 20 (42%) |
| Active lidar practitioner | 27 (87%) | 63 (89%) | 32 (67%) |

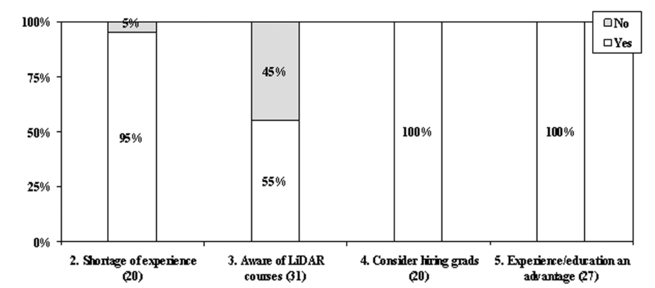


Figure 1. Summary of responses to questions 1 to 5 in ASPRS questionnaire. (Number in brackets denotes total number of Yes or No responses).

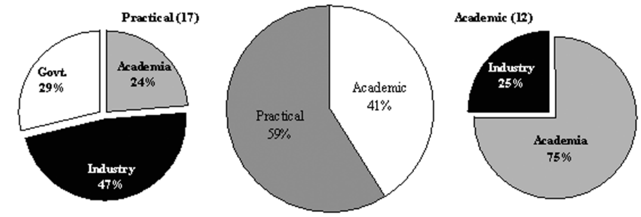


Figure 2. Stratified responses to question 6: Which do you think is more important in hiring a staff member/graduate student for your lidar team: academic training or practical experience?

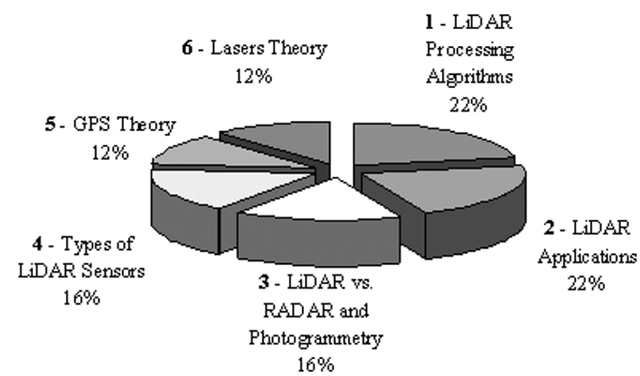


Figure 3. Ranked response to question 7 concerning perceptions on most important topics to be included in a course on lidar.

actually have the appropriate skills. Despite this demonstrated need for lidar education and experience in the community, only just over half the respondents (55 percent) were aware of any lidar training opportunities.

When asked whether or not "practical experience" or "academic training" were more important in the hiring of lidar personnel, there was a tendency towards practical experience (59 percent) in the overall response (Figure 2). However, after analysing the response by sector, a clear stratification was apparent whereby 75 percent of those favoring academic training were academics, and 76 percent of those favoring practical experience were either from industry or government sectors. Such stratification is likely a function of different perceptions of the importance of pragmatic versus intellectual problem solving abilities within each sector, and as such, this result could be anticipated.

Concerning potential topics for a course on lidar (question 7), the responses were varied and the ranking of importance was not strong (Figure 3). Lidar processing algorithms and lidar applications were ranked highest while GPS/INS and laser theory were ranked lowest. The reasons for the rankings were not explored, but lidar processing and applications could be perceived to be of high importance because understanding what lidar can do and how to extract information from the data are of the most intrinsic value to the end user, and therefore of importance to the service provider. GPS and INS theory, on the other hand, while important from a raw data processing point of view is not unique to lidar mapping and such knowledge is readily accessible in unrelated programs. Again laser theory is accessible outside the lidar mapping and imaging community, and although some understanding might be necessary to trouble shoot the technology in the field, or to more fully appreciate what information is displayed in the data, such information is not necessary for simple sensor operation, data integration or data manipulation.

#### AGRG Questionnaire

Responses to the "yes/no" type answers in the AGRG questionnaire are summarised in Table 2. Most AGRG questionnaire respondents that expressed any opinion agreed with the finding of the ASPRS questionnaire that it is difficult to find appropriately qualified or experienced personnel to fill lidar positions (75 percent), and this observation demonstrated little stratification across sectors (60 percent government to 86 percent academic). Also in agreement with the results of the ASPRS questionnaire and across all three sectors was the finding that the majority of AGRG respondents agreed there was a need for independent lidar training (92 percent). In answering questions 4 and 5, a little over half indicated that they were aware of or performed some kind of lidar training themselves, whether it be in house training of staff, open to students and/or the public, or for paying clients. These results were again consistent with the results of the ASPRS questionnaire (question 3, Figure 1), however, there was a slight stratification in the AGRG results suggesting that the industry community is most active in (68 percent) and more aware of (71 percent) training opportunities, while government respondents demonstrated the least activity (30 percent) or awareness (40 percent).

The most common format of lidar training known to the respondents of the AGRG questionnaire (question 6) with

Table 2. Yes/No Responses for Questions 2 to 5 in the agrg Questionnaire. Responses of "Don't Know" and "Maybe" Have Been Considered Neutral and Not Presented in the Analysis. (Number in Brackets Denotes Actual Number of Yes/No Responses)

| | All Responses | | Stratified Responses: Academic | | Government | | Industry | |
|---|---|---|---|---|---|---|---|---|
| Question | Yes | No | Yes | No | Yes | No | Yes | No |
| 2 - Is it difficult to find experienced personnel? (36) | 75% | 25% | 86% | 14% | 60% | 40% | 71% | 29% |
| 3 - Is there a need for independent training? (54) | 92% | 8% | 84% | 16% | 100% | 0% | 100% | 0% |
| 4 - Are you aware of any lidar training? (71) | 54% | 46% | 58% | 42% | 40% | 60% | 71% | 29% |
| 5 - Do you conduct lidar training? (71) | 51% | 49% | 44% | 56% | 30% | 70% | 68% | 32% |

38 percent of the vote was conferences and workshops (Figure 4). Academic courses (21 percent), manufacturer (21 percent), and independent (17 percent) training programs displayed similar proportions but lagged some way behind, with service provider training being the least familiar training format (3 percent). These perceptions on the formats of available training are likely a function of their relative accessibility; i.e., conferences and workshops tend to be short duration, cost effective, and open to the public, while access is somewhat limited to each of the other training formats noted. In the case of academic programs, access tends to be exclusive to enrolled students; manufacturer training exclusive to clients who have purchased a sensor; independent training is likely to be accessible but at a cost; while service provider training is most likely to be available to clients (or potential clients) of data collection services.

In response to the question "*who most needs or would be the biggest user of lidar training?*" (question 7) the cumulative responses for the four options (commercial end users, service providers, academics or government) demonstrated no clear ranking with the share of the vote ranging from 20 percent for government to 28 percent for end users (Figure 5). However, when the results were stratified, it was clear that respondents from each sector tended to believe they most needed training; with 48 percent of government respondents believing that government employees would most benefit from lidar training, 38 percent of academics believing they would most benefit, while 41 percent and 36 percent of industry respondents believing that commercial end users and service providers, respectively, would most benefit. This does not necessarily suggest that members of each sector believe that they have the least amount of training, but rather relative to other sectors they think they need it the most. These results corroborate earlier findings concerning the widespread perception of a lack of experience and the need for training (Figure 1 and Table 2), but more specifically indicate that there is a shortage of training opportunities across the entire lidar community.

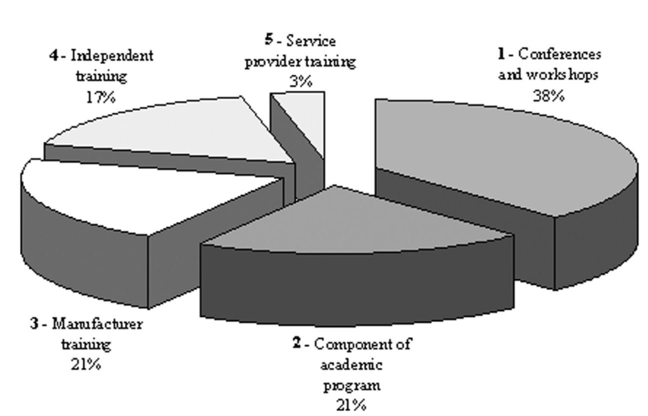


Figure 4. Ranked distribution of formats of all lidar training programs (question 6) known to 33 AGRG respondents.

Although the options for ranked lidar training components differed in ASPRS question 7 (Figure 3) and AGRG question 8 (Figure 5), both sets of answers suggest that "lidar data manipulation and end user applications" are important topics. However, investigating these results by sector (Figure 5) indicates that although government and academic respondents hold this opinion, members of industry tend to place at least as much importance on the more practical options of data processing, project management, and sensor operations. This stratification of the results likely mirrors the common lidar activities within each sector. Government and academic researchers tend to be more concerned with the application of data to a specific question or problem, while the industry sector is more concerned with operational aspects of the technology and data collection. Of most significance, is that these results demonstrate that the actual training needs of each sector are different.

Consistent with the findings of ASPRS question 6, 72 percent of the respondents to AGRG question 9 from all sectors agreed that maximizing opportunities for practical hands on experience was by far the most important design consideration for any lidar training program. Maximizing theoretical content was a distant second for all sectors and issues of cost and attendance were considered low priorities. (It is worth noting however, that while cost and attendance numbers might be a low priority to those considering taking training, these could be critical considerations for those actually designing and implementing a training program.) Further supporting evidence for the value of practical experience, was the finding that 36 percent of all respondents believed that relevant industry experience was the most important attribute of anyone wishing to take lidar training (question 10). In the overall rankings, a degree qualification was second (31 percent) and vocational diploma third (23 percent). There was little stratification across sectors, although industry placed diploma second (27 percent) slightly above degree (25 percent). Few respondents believed it appropriate to offer lidar training to anyone without relevant qualifications or experience.

AGRG questions 11 and 12 are concerned with the format that lidar training could take. The results from question 11, suggest that the optimal length of lidar training is anywhere from one day to a single term or semester (Figure 5). Most believed that less than a whole day was insufficient while a whole year was too much. There was very little stratification in these results apart from a gradual decline in academic ranking as duration increased from day to term (37 percent

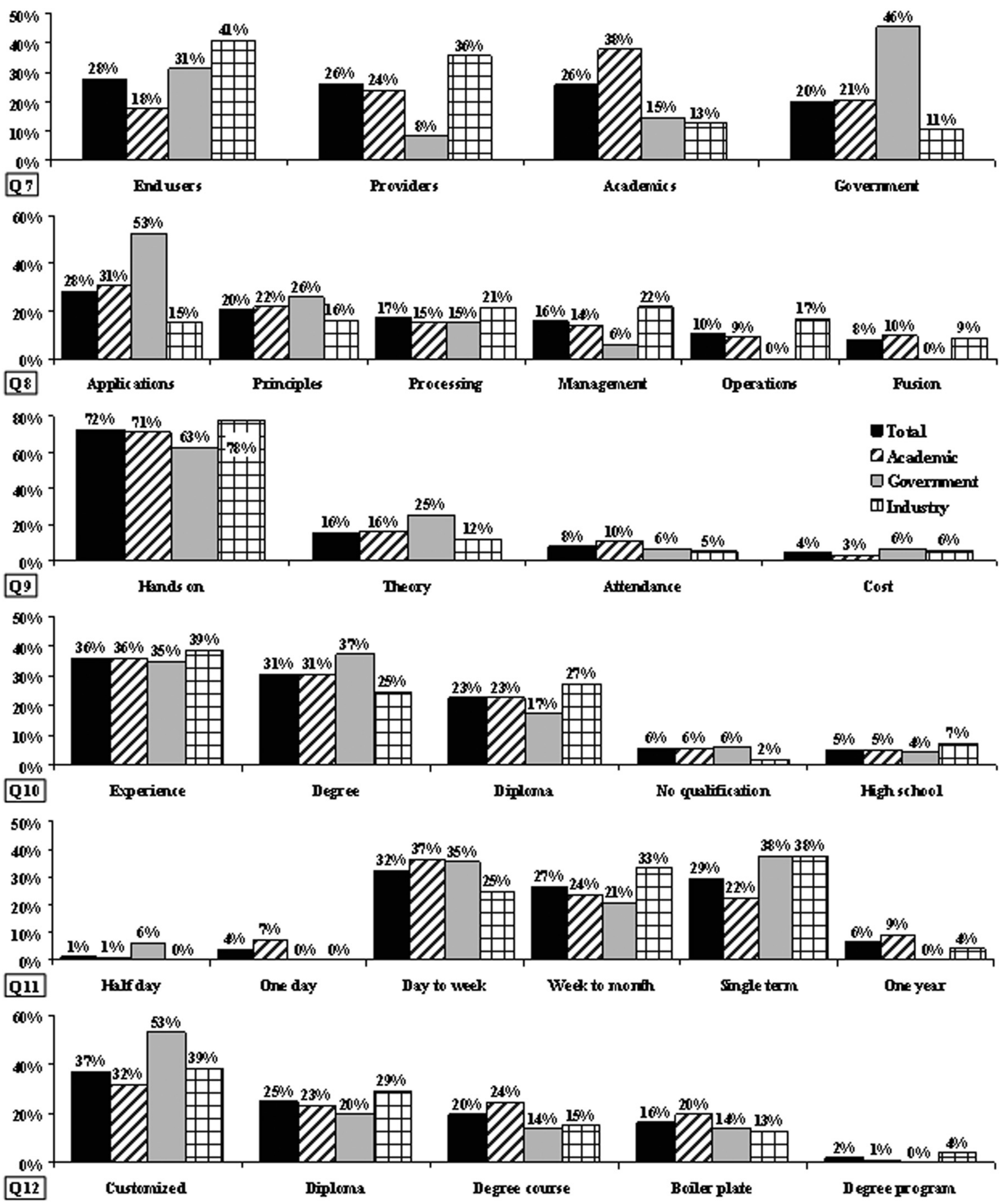


Figure 5. Summary of responses to AGRG questions 7 to 12, stratified by respondent sector: (7) Greatest need for lidar training?, (8) Priority topics?, (9) Most important when designing a training program?, (10) Appropriate entry qualification?, (11) Appropriate duration?, and (12) Most appropriate format.

to 22 percent), whereas industry rankings actually increased with duration (25 percent to 38 percent). This observed difference in tendency suggests that the industry sector believes more time is needed to meet their training needs, relative to academics that believe their training needs can be met in a slightly shorter time frame. Responses to question 12 were generally consistent, in that the duration of the favored formats could all fit into the optimal time frame indicated, whereas a full degree program, which is typically at least three years in duration, received very little support across all sectors. Customized training at site of client was considered the most appropriate format for lidar training by all three sector respondents (37 percent), while second place ranking went to vocational diploma training (25 percent), then degree level course (20 percent) and finally boiler plate training (fixed curriculum format) at training institute (16 percent). There was little sector stratification apart from between the industry and academic respondents to the second two rankings; industry favored diploma to degree by 29 percent to 15 percent, whereas an insignificant reversal was observed in the academic tendency from 23 percent to 24 percent, respectively.

## Discussion

Discussion will focus on addressing the four main questions posed in the introduction and discussed at the CLART workshop, while referring to the results of the more targeted questions contained in the questionnaires.

### What Training is Currently Available?

A little over half of all questionnaire respondents (Figure 1 and table 2) and workshop participants were aware of lidar training courses. The institutions or companies providing the training are listed in Table 3. This list is not thought to be complete and given there were only 128 individuals surveyed, the identification of 27 institutions that provide some form of training could suggest that there is a lot of lidar training available. However, it should be noted that most courses deal with a small part of the overall lidar project workflow (e.g., specific application areas such as forestry or hardware/software training only), and only three of the programs listed offer the possibility for *hands on* operational training.

Of the seven companies identified as providing some form of lidar training, six are either manufacturers, software developers, or service providers and are therefore in competition for sales. Training delivered by these companies will tend to be specific to the product they are selling and is unlikely to be comprehensive or completely objective. The academic institutions listed provide educational training primarily to enrolled students, and as such the training tends to be somewhat exclusive and not available to the general public.

### Who Needs Lidar Training?

It was apparent from the questionnaire responses that despite the training opportunities already identified, there is a strong need for lidar training, and this need was identified within all sectors of the community from manufacturers to service providers to government end users and academic researchers. Unfortunately, these data did not allow for a reliable estimation of either the absolute or relative size of need for each sector, but it is possible to at least start to differentiate at a high level between two types of needs; those of the lidar service industry and those of the end user community.

Mr. Eric Liberty (Optech, Inc.) provided some insight into the potential size of the growing service provider industry at the CLART workshop:

"*Optech plans on selling around 100 systems worldwide over four years. This translates to an approximate need for operational training for 300 to 400 people, with about half of these in North America*."

The TMSI lidar market report (TMSI, 2005) estimates more conservatively that by 2010 the entire manufacturing industry will add approximately 80 new systems to the global market. If we assume that an individual sensor requires three skilled lidar employees (e.g., manager, operator, data processor) for normal operations, and we assume the TMSI estimate is conservative, while the Optech estimate is representative of their current market share of 47 percent (TMSI, 2005), then by 2010 the number of new service provider personnel globally lies in the range 250 to 750 individuals.

This speculation on the predicted growth of the service provider sector can also provide a basis for estimating growth within the end user community. If we conservatively

Table 3. Summary of Academic Institutions and Private Companies Identified by Participants of CLART and Respondents to Both Questionnaires as Providing Some Form of Lidar-related Education or Training

| Academic Institution | Department | Region |
|---|---|---|
| Agricultural University of Norway | Dept. of Ecology and Natural Resource Management | Europe |
| Helsinki University of Technology | | Europe |
| Institute of Geomatica | | Europe |
| Katholiek Universität Leuven | | Europe |
| Technische Universität Dresden | | Europe |
| Technische Universität München | Ecosystem and Landscape management | Europe |
| Technische Universität Wien | | Europe |
| University of Cambridge | Landscape Assessment | Europe |
| California State University Fresno | Civil and Geomatic Engineering | N. America |
| Centre of Geographic Sciences | Applied Geomatics Research Group | N. America |
| Colorado State University | Forestry | N. America |
| Mississippi State University | Forestry | N. America |
| Ohio State University | Dept. of CEECS | N. America |
| Queen's University | Geography | N. America |
| Texas A & M university | Forest Science | N. America |
| University of Florida | Geomatics Engineering | N. America |
| University of Quebec at Montreal | Geography | N. America |
| University of South Carolina | Geography | N. America |
| University of Washington | Forest Resources | N. America |
| Hong Kong Polytechnic | | Rest of World |
| Private companies | Sector | |
| Terrasolid Ltd. | Software developer | Europe |
| Leica Geosystems | Manufacturer | N. America |
| Mosaic Mapping Ltd./Terrapoint | Service provider/Manufacturer | N. America |
| Optech, Inc. | Manufacturer | N. America |
| Otterburn Geographic | Consultancy | N. America |
| Geokosmos | Service provider | Rest of World |
| iQevolution | Software developer | Rest of World |

assume that the client base for a single service provider increases by approximately five new clients per year and that each client has two employees (e.g., manager and data processor) or students that would benefit from lidar training, this suggests that the number of new end users directly involved in lidar-related activities from 2005 to 2010 could lie in the range 2,500 to 7,500. However, it should be noted that even if these numbers provide reasonable estimates of the amount of new activity within the lidar service provision and end user communities, this does not imply that these individuals would be in the market for training. These numbers also do not provide any basis for estimating the proportion of those currently within the lidar community that need training or education. All that can be concluded with any certainty is that there is currently a need, this need is likely high, and will continue to grow for some years.

To more specifically identify who, within the service provision and end user communities, would actually benefit from training, it is useful to consider the workflow of a typical lidar data collection project from conception to completion (see Table 4). The example provided could conceptually be for a coastal mapping project to assess flood impact risks. In such a scenario, the end user might be a government agency and the service provider any commercial lidar operator. However, regardless of the nature of the actual agencies or scope of the project, the steps listed below should be common (or at least have analogs) across a wide variety of mapping projects and sectors.

Although nine discrete steps in the workflow have been identified (Table 4), it is likely that in some projects steps will be added, some steps might be merged and some potentially missed altogether. However, regardless of the order and division of steps taken in the workflow, most of the actual tasks listed will take place on some level (either explicitly or implicitly), and someone will have to be responsible for performing these tasks. In the example provided (Table 4), six categories of primary responsibility have been defined: (a) EUC: a person, agency, client or policy that identifies lidar as a potential solution to a problem or question; (b) EUM: the end user project manager that is responsible for initiating and monitoring the project; (c) EUD: the end user employee responsible for the actual handling of lidar data and generation of information that can be used by EUM to address the problem defined by EUC; (d) SPM: the service provider project manager who looks after high level project logistics, client interaction, and coordinates mission planning activities; (e) SPO: the service provider sensor operator responsible for day to day operations and lidar maintenance; and (f) SPD: the service provider data processor responsible for data processing and formatting activities. These six areas of responsibility might not be evident in any given project, as in small projects (e.g., some academic data collections) the EUM could also be EUC and EUD combined, and in small service provider companies, it is common to find the SPM, SPO, and SPD duties conducted by one or two people. Conversely, in larger projects and companies, the numbers might be increased. However, the point to be made here, is that these six areas of responsibility are sufficiently distinct, whether actually performed by six individuals or not, that they are indicative of the categories of individual that might benefit from some form of lidar training or education.

### What Needs To Be Trained?

Questionnaire responses to these types of questions are illustrated in Figures 3 and 5, where the common response was to rank applications and data processing/manipulation skills as high. This view was corroborated and expanded upon by some of the comments accompanying the ASPRS and AGRG questionnaire responses. For example Dr. Michael Hodgson (University of South Carolina) commented that:

"*There are several very fundamental issues related to map scale (e.g., resolution), sampling density, and sources of*

Table 4. A Typical Workflow for a Lidar Project from Conception to Completion

| Step | Typical End User Tasks | Typical Service Provider Tasks | Primary Responsibility |
|---|---|---|---|
| 1 | *Project definition*<br>Identification of a problem for which lidar provides a potential solution. | | End user client (EUC) |
| 2 | *Request for Proposal (RFP)*<br>The scope of work is defined and submitted to public tender. | | End user project manager (EUM) |
| 3 | | *Proposal submission*<br>Project logistical requirements are assessed and a costing proposal developed and submitted. | Service provider project manager (SPM) |
| 4 | *Proposal review*<br>Proposal submissions evaluated and contract negotiated/awarded. | | EUM |
| 5 | | *Mission planning*<br>Data collection logistical planning finalized and project initiated. | SPM |
| 6 | | *Data collection*<br>Lidar sensor installation, daily flight planning, and sensor operation. | SPM and lidar operator (SPO) |
| 7 | | *Data processing and delivery*<br>Sensor calibration, data integration, quality control, output, formatting, and delivery. | SPM and lidar data processor (SPD) |
| 8 | *Data checking*<br>Data accepted, archived, and quality assessment performed. | | End user data manager (EUD) |
| 9 | *Information extraction*<br>Data manipulated to address the problem identified in step 1 | | EUD |

*errors in the creation of surface fields (e.g., terrain, canopy, multi-story, etc.). These issues go beyond lidar, per se, but should be foundational material either in your text/course or as a prerequisite.*"

Dr. Thomas Schneider (Technical University of Munich) noted that all of the following were important topics for a lidar course:

"*Cost/benefit analysis, scaling issues (point density), modeling issues (DEM/DSM* for water run off, forest growth, etc.)"

However, it was also noted in the AGRG questionnaire responses (Figure 5) that industry respondents did not share the perception of high importance for application related issues and data manipulation techniques. For example during the CLART workshop, in addition to aspects of operational training for members of the service provision sector, there was also much discussion about the legal ramifications of training, the teaching of standards and issues related to safety. Dr. Benoit St-Onge (University of Quebec at Montreal) summarized the central issue in his comment:

"*There are different types and levels of expectations between academics and industry players. Training in the area of lidar might be multi-levelled.*"

If we consider this statement in the context of the six previous categories of lidar project responsibility listed in Table 3, it is quite clear that the types and levels of expectation between and within end user and service provider categories will indeed differ and be multi-levelled. To assess the types and levels of training needed within each area of primary responsibility, it is useful to consider the most important and unique lidar related tasks performed within each category.

*End User Client (EUC)*
The "end user client" typically plays a *hands off* role within the lidar project work flow, and as such, probably has little need for an in depth knowledge of lidar technology, operations or data processing. However, such a person probably would benefit from knowing what lidar can do and what types of questions/problems it can be used for; i.e., an overview of applications, project costs, and timing limitations might be all that is needed at this level.

*End User Project Manager (EUM)*
Typical responsibilities at this level are developing a request for proposals (RFP), reviewing submitted proposals, liaising with the chosen service provider and supervising (but not necessarily conducting) the manipulation of processed lidar data to extract information, and create new end user products. It is not necessary that EUMs play a *hands on* role in the data collection and manipulation components of the project work flow but beyond applications an understanding of the data accuracy limitations, data formats, file sizes, software, and hardware requirements for data manipulation are required to ensure that the end user maximizes the return on their data collection investment. This level of responsibility is critical to the success of the project both for the end user and service provider because if the EUM has unrealistic expectations or provides insufficient resources to manage the project at the end user level, then not only does the project run the risk of not meeting its objectives but also the service provider's reputation could be damaged. There is a strong need, therefore, for training in EUM responsibility areas such as: (a) lidar project RFP development; (b) data accuracy expectations and potential sources of error; and (c) hardware/software project resourcing and data management.

*End User Data Processor (EUD)*
Many of the skills related to end user data manipulation are not necessarily specific to lidar; for example digital elevation model (DEM) generation, terrain analysis, image processing, and geographical information system (GIS) manipulation skills are taught in colleges and universities around the world. However, it is common for many end users to find themselves somewhat overwhelmed by the sheer size of data, and new skills often need to be learned to more efficiently handle the data. In addition, in order that the end user can perform an independent check of the service provider's claimed data accuracy, skills related to lidar quality assessment (QA) are also needed.

*Service Provider Project Manager (SPM)*
Many tasks at this level of responsibility, such as proposal submission, client liaison, project logistics, airborne operations, flight planning, and data management are not unique to lidar projects. However, the SPM also needs to have a working knowledge of the lidar sensor technology, be able to step into the shoes of the SPO and SPD if necessary, and ideally some knowledge of the application domain that the client is working in. Essentially, the SPM has a very wide range of skills related to lidar operations but does not necessarily need to be expert in any one area. The suite of skills needed for this kind of position is rarely taught but more commonly learned *on the job*.

*Service Provider Sensor Operator (SPO)*
The SPO needs to know everything about the installation, operation, and day-to-day maintenance of the lidar sensor. Due to the high level of cutting edge technology contained within a lidar sensor, one of the important skills required of the SPO is the ability to troubleshoot a variety of potential sensor problems in the middle of a project. Typically, SPO responsibilities also overlap with the SPM in terms of flight planning and survey design, and with the SPD on some aspects of preliminary data processing or sensor calibration. There are several types and brands of lidar sensors currently available and each differs in terms of its operation and *user friendliness*. It is typical for preliminary sensor operation training to be conducted by the manufacturer, and the finer skills related to troubleshooting learned *on the job*.

*Service Provider Data Processor (SPD)*
SPD responsibilities and the associated software used are typically unique to the lidar project workflow and require specific knowledge of the integrated data streams (e.g., GPS, INS, laser range, scan angle) to derive output that can be handled by the end user. The SPD needs to be expert at calibrating the sensor, knowledgeable about coordinate systems and datums, be able to conduct quality assessment/control (QA/QC) and manage large project data sets. In addition, a high level of computer acumen, knowledge of various geomatics related software packages, and networking skills are highly valuable. Some of these general skills are taught in various college and university programs, but those specific to lidar data integration, sensor calibration, or data filtering are typically only available in introductory form from sensor manufacturers and software vendors.

It is obvious that there are very different training requirements for the SP and EU personnel, and even within each of these communities. The design of any lidar training course needs to first assess whether the training is aimed at the service provider or at the end user community and then further identify whether or not the training is aimed at specific members of the category.

#### What Format of Training is Needed?

It is apparent from the responses to ASPRS question 6 (Figure 2) that practical experience tends to be favored over academic training for lidar personnel. Also, *hands on* opportunities were considered a more important attribute of a lidar training program than theory (AGRG question 9, Figure 4). These observations suggest that training needs in the lidar community are more vocational than academic. This is corroborated by the response to AGRG question 10, where experience rather than academic qualification was considered of higher importance for those undertaking lidar training. Further, the appropriate duration for lidar training would appear to be greater than one day but up to a single term or semester. All of these observations have an important bearing on the format that training should take but from the discussion above dealing with *who* and *what* needs to be trained, it is clear that no single format of lidar training would suit all members of the community.

*Service Provider Model*

While discussing potential training formats at the CLART workshop, Mr. Bob Fowler of Lasermap Image Plus provided a service provider perspective on this need suggesting that three levels of training would be appropriate:

1. System operation training: short duration;
2. Data processing and manipulation training: intermediate period;
3. Project based training: longer time period.

The skills developed at each of these training levels are in many ways analogous to those necessary to take on the responsibilities of the SPO, SPD, and SPM, respectively, with the duration of training increasing with responsibility. Combining the data obtained on training needs, duration, and formats, a training model that meets the service provider needs might be to target each area of responsibility individually and tailor a vocational *skills oriented* program (or modules within a program) for each; for example:

1. SPO: Sensor technology and survey operations – Up to one week;
2. SPD: Sensor calibration, data integration, quality control – Greater than one week;
3. SPM: All of the above within an end-to-end project framework – Up to one term.

*End User Model*

Although the model above might meet the needs of the service provider sector, those of the larger end user community differ. For example, in Figure 2 it is demonstrated that the majority of academic responses did not see *practical* as preferable to *academic* training. Also, at the EUC and EUM levels of responsibility within a lidar project, specific lidar skills are less important than knowledge on technological capabilities such as data accuracies, costs, and applications. Therefore, the kind of vocational training proposed above would likely provide redundant skills, yet not cover the required knowledge for anyone at the EUC and EUM level. Similarly, even though some SPD and EUD skill requirements overlap, the needs for data management/manipulation and information extraction at the EUD level generally require expertise in different software environments. Another complicating factor is that potential end user applications are so widely variable (e.g., power line catenaries, DEM runoff modeling, engineering cut and fill computation, forest canopy assessments), that the skills required at the EUD level might be highly specific to the application environment.

Given the wide variety of training and knowledge needs of the end user community, it is difficult to identify a single training format to meet these needs. However, as with the service provider sector, there are some critical lidar specific needs associated with each level of responsibility. If we also scale these needs with an appropriate duration to provide sufficient experience and knowledge to carry out tasks at each level of responsibility, we arrive at a similar model to that proposed above but this time the duration decreases with overall responsibility and increases with level of *hands on* involvement:

1. EUC: Overview of technology and applications – Up to one day;
2. EUM: The above plus RFP development, project resourcing and costs – Greater than one day;
3. EUD: Project based data manipulation and management skills development – Up to one term.

*Putting It All Together*

In both models, it is clear that those at the SPM and EUD levels would benefit from the preceding shorter duration training components, also. Each model, therefore, can be considered the basis for a complete lidar training program, where step one is introductory and everyone participates for a short duration, through to step three where there are fewer participants staying for the long haul. Such hierarchical training is in effect modular, where each module builds on the last and differs in length and depth. Although such models might meet the needs of the service provider and end user lidar communities, it is challenging to build the required flexibility into traditional college diploma or university degree program curricula.

The observed perceived importance of skills and experience over knowledge identified in this study suggests that vocational training might be more appropriate for some lidar-related responsibilities at the SPO, SPD, and EUD levels, while it might be expected that more academic qualifications would be sought at the SPM and EUM levels. In either case, if we are looking for an end-to-end program that caters to all levels in the suggested hierarchies, it is likely that neither a college diploma nor a degree course will meet these sector based needs. This was effectively identified in the responses to AGRG question 12 (Figure 5) where more than a third of respondents believed that some form of *customized* training was most suited to the training needs of the lidar community. This is not to say that vocational diploma or academic degree level training and education is not relevant but rather given the identified needs of the lidar community, neither of these formats provides the optimal mix of theory and skills development within an appropriate time frame. Indeed, suggested in the responses to AGRG question 10 (Figure 5), is that those entering the lidar community and needing training likely already have extensive industry experience, a diploma or a degree, and so the training expounded in models one and two is unlikely to be a replacement for any of these experiences or qualifications.

As to the specific format such training should take, the data collected provide no clear answer. It could be argued that for end users already possessing a degree, a graduate program with emphasis on lidar and geomatics could be appropriate. For those with vocational diploma training or extensive industry experience in a geomatics-related discipline, the required training could be made available in a dedicated lidar advanced diploma program. However, although such programs might meet the needs of some people, they do not adequately address the needs of those already within or on the periphery of the lidar community that do not have the time or inclination to go back to university or college. For these, some form of targeted training that meets their specific needs is highly desirable and, from the data collected, not readily available.

For those in the SPO and SPD categories of project responsibility, manufacturer or *on the job* training is often available but this could be supplemented with independent training to provide background into basic principles, project management, and software skills related to these individual areas of the overall lidar workflow. This type of supplemental training could be achieved within a relatively short-term *practicum* environment. Many of the knowledge-based needs of end users in the EUC and EUM categories can be met in short seminars and lectures providing an overview of lidar technology and applications. These kinds of seminars or workshop are already popular at industry and academic conferences but are frequently delivered by members of the service provider or manufacturer industry and therefore often take on the appearance of a *sales pitch*. To improve the objectivity and credibility of the information in lidar overview seminars and workshops, there is a need for this type of training to be delivered by independent sources.

While considering the needs of the *hands on* EUD members of the end user community at the CLART workshop, Eric Liberty of Optech, Incorporated asked the following question:

"*Has the user community ever entertained the placement of students?*"

This question led to further discussion on the development of student practicum programs and internships. The concept of an internship carried out at an institution of higher learning but closely tied to the needs of a professional sponsor (e.g., industry or government) was generally thought to provide a suitable solution to the needs of those requiring more in depth training; namely the EUD and SPD responsibility categories.

## Concluding Remarks

Despite a general lack of appropriate skill sets in the employment market for sensor operators (SPO) and data processors (SPD), the relatively small size and moderate growth of the industry, and a tendency for employees to be trained *in house* or by sensor manufacturers, means that the need for training of personnel on the front lines of the service provider sector is limited. Needs are strongest in the end user communities at the project initiation (EUC and EUM) and data delivery to manipulation (EUD) stages of a project. To increase confidence in the technology and data, the end user community needs to be made more aware of the technology and applications so that they know better how to: (a) specify a lidar data collection "request for proposals"; and (b) turn raw data into the application information that they require. Some data collection companies do provide these types of educational services to their potential or existing clients. However, with a growing and competitive industry and an ever-expanding end user community, the possibility for perceived conflict of interest indicates there is a need for independent educational facilities to bring lidar into the mainstream curriculum. With only four academic facilities worldwide owning and operating their own scanning lidar sensors, and the tendency for institutions to only grant access to the technology to select few students and collaborators, there is an obvious challenge in bringing all aspects of lidar operations and data manipulation to a widely available mainstream curriculum.

In response to the training needs and some of the potential solutions identified in this study, the Applied Geomatics Research Group (AGRG) and Canadian Consortium for lidar Environmental Applications Research (C-CLEAR) are currently developing a suite of training programs ranging from short seminars to multiple day workshops to project based internships and advanced diploma training that meet the requirements of the lidar community. Building on over ten years of combined *hands on* experience in lidar and GPS survey operations, geomatics higher education, and applied lidar research, AGRG and C-CLEAR will utilize their airborne and ground based lidar technologies and range of software tools to provide comprehensive training opportunities to those in any of the six end user and service provider responsibility categories identified. C-CLEAR and AGRG are also partnering with members of the wider research community to collaborate on pilot studies and applications development with the objective of educating end users and familiarizing them with lidar project specifications and data manipulation techniques. The next steps in meeting the education and training needs of the lidar community will be in building curriculum around professional industry best practice guidelines and certification initiatives.

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