Surveying Body of Knowledge

Joshua GREENFELD, Israel

SUMMARY

A profession is founded on knowledge, skills and education. The required knowledge, skills and education to practice within a profession should be defined in a body of knowledge of that profession. Defining a body of knowledge can be done in general terms such as outlining skills, attitudes and knowledge that will enable an individual to become and remain a professional expert. The other way to define a professions' body of knowledge is to compile a detailed list of theories, methodologies, technologies and procedures that have to be mastered for present professional practice. It can be easily argued that perhaps the body of knowledge should be developed using both approaches. Using both approaches the body of knowledge will consist of a macro level body of knowledge with conceptual long term definitions and a micro level body of knowledge that defines the current needs for professional practice.

The American Congress on Surveying and Mapping (ACSM) and the North American Surveying Educators organization have embarked on an important task of developing a body of knowledge for surveying. Currently the body of knowledge committee is developing one general body of knowledge and five specific ones in the areas of positioning, imagery, GIS, land development and law. The paper summarizes the current status of this body of knowledge.

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INTRODUCTION

As positioning technologies evolve and mapping capabilities become prevalent through GPS and GIS, there is a growing perception that "everyone can do surveying". All one has to do is to purchase a GPS receiver, take some training in GIS (or CAD) software, start to collect positions of land features and produce maps. Such a perception of what a surveyor does can have a devastating impact on the profession. It arises primarily from the lack of understanding of what a surveyor does and what is the knowledge base and skills on which the profession is founded. Not only the general public and the geospatial community lacks the understanding of what knowledge and skills a surveyor possesses but even the surveying communities in different countries are not in agreement on this matter. Therefore, it is of utmost importance to establish the body of knowledge that defines the surveying profession. In order to do that we first need to examine closely what makes an occupation a profession, followed by defining the characteristics of the surveying profession. This will make it clear that not everyone can do surveying.

There are several definitions for a profession. One of them is the one adopted at Annual General Meeting of the Australian national organization of professional associations, 26 May, 1997. It states that:

> *A profession is a disciplined group of individuals who adhere to ethical standards and hold themselves out as, and are accepted by the public as possessing special knowledge and skills in a widely recognized body of learning derived from research, education and training at a high level, and who are prepared to apply this knowledge and exercise these skills in the interest of others.* [http://www.professions.com.au/definitionprofession.html]

Based on the above definition it follows that in order for a group of individuals to be considered as professionals they must be accepted by the public as possessing special knowledge and skills in a widely recognized body of knowledge. The surveying profession is not or should not be different from any other occupation that that wants to be considered as a profession. Consequently, the knowledge and skills that are required in order to become a professional land surveyor have to be defined.

There are two primary approaches for defining a body of knowledge. The first is to develop a general outline of skills, attitudes and knowledge that will enable an individual to develop specific understanding and abilities necessary to become and remain a professional expert. The other way to define a professions' body of knowledge is to compile a detailed list of theories, methodologies, technologies and procedures that have to be mastered for present professional practice. It can be easily argued that perhaps the body of knowledge should be developed using both approaches. Using both approaches the body of knowledge will consist of a macro level body of knowledge with conceptual long term definitions and a micro level body of knowledge that defines the current needs for professional practice.

A first attempt to define a macro level body of knowledge for surveying in the U.S. was presented in (Greenfeld and Potts, 2008). The paper outlined a rather general approach for the body of knowledge for surveying, which is to some extent consistent with the Accreditation Board for Engineering and Technology (ABET) outcome assessment approach introduced in Criteria 2000 [ABET 2000]. In the ABET approach, objectives and outcomes are to be defined without specific prescribed implementation details. A similar approach for defining the body of knowledge was adopted by some professional societies such as the American Society of Civil Engineers (ASCE) [ASCE 2004 and 2008].

To complement the macro level definition of the surveying body of knowledge it is beneficial to define the micro level surveying body of knowledge. The micro level definition is also needed because of the recurring challenges the surveying profession is facing from others such as Civil Engineers or GIS practitioners. A micro level body of knowledge for surveying would help the profession to define its uniqueness. One available source for micro level body of knowledge for surveying is the one compiled by the US National Council of Examiners for Engineering and Surveying (NCEES). It is used to determine what knowledge must be mastered in order to qualify as a surveyor-in-training or as a professional surveyor. The fundamentals of surveying and professional practice licensing exam are based on this knowledge base [NCEES]. This approach requires periodic updating of the knowledge base following changes in technology and professional practice. The drawback of the NCEES knowledge base is that it is based on polling the surveying community on current practices of surveyors. In other words the licensing examination is based on what surveyors do now from the perspective of practicing surveyors. A better knowledge base can be established based not only of current practices but on the science of surveying and the visionary role of the professional in the 21st century. A micro level approach for defining the body of knowledge for GIS was adopted by the Association of American Geographers (AAG) and the University Consortium for Geographic Information Science (UCGIS) [AAG 2006].

The American Congress on Surveying and Mapping (ACSM) and the North American Surveying Educators organization have embarked on the important task of developing a body of knowledge for surveying form the U.S. perspective. Currently the body of knowledge committee is developing one general body of knowledge complemented by five specific ones in the areas of positioning, imagery, GIS, land development and law. In this paper the macro level surveying body of knowledge and early findings of the micro level body of knowledge will be presented. The GIS body of knowledge for surveying will be used as a general model in which the other four bodies of knowledge will be developed.

THE SURVEYING BODY OF KNOWLEDGE

One of the first questions that have to be addressed is what is surveying in general and what is the role of the profession surveyor in particular. The answer to this question will enable us to develop a general overview of the surveying body of knowledge and allow us to focus on subsets of bodies of knowledge that define the micro level.

One obvious source for understanding the role of surveying is the FIG definition of surveying. The FIG definition lists 11 tasks that fall under the umbrella of the surveying profession. Based on this definition, five specific subsets of bodies of knowledge were selected for surveying. The five subsets are:

- Positioning body of knowledge – including Geodesy, GPS and other field surveying data collection
- GIS body of knowledge – including mapping and cartography
- Imagery body of knowledge – including photogrammetry, remote sensing and other image/sensor based technologies such as laser scanners
- Law body of knowledge – including boundary, real property and business law
- Land development body of knowledge – including construction, planning and developing and urban/rural/regional areas

The table 1 shows the relationship between these body of knowledge subsets and the FIG dentition of surveying. It is important to mention here that task 10 of the FIG definition that deals with assessment of value and the management of property was not included in the proposed surveying body of knowledge because in the U.S.(and some other countries as well) surveyors are not licensed to perform this task.

Subset	FIG task
Positioning	1. The determination of the size and shape of the earth and the measurement of all data needed to define the size, position, shape and contour of any part of the earth and monitoring any change therein. 2. The positioning of objects in space and time as well as the positioning and monitoring of physical features, structures and engineering works on, above or below the surface of the earth. 3. The development, testing and calibration of sensors, instruments and systems for the above-mentioned purposes and for other surveying purposes.
Imagery	4. The acquisition and use of spatial information from close range, aerial and satellite imagery and the automation of these processes.
Law	5. The determination of the position of the boundaries of public or private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.

Subset	FIG task
GIS	6. The design, establishment and administration of geographic information systems (GIS) and the collection, storage, analysis, management, display and dissemination of data. 7. The analysis, interpretation and integration of spatial objects and phenomena in GIS, including the visualisation and communication of such data in maps, models and mobile digital devices.
Land development	8. The study of the natural and social environment, the measurement of land and marine resources and the use of such data in the planning of development in urban, rural and regional areas. 9. The planning, development and redevelopment of property, whether urban or rural and whether land or buildings. 10. N/A 11. The planning, measurement and management of construction works, including the estimation of costs.

Table 1. The relationship between the proposed body of knowledge subsets and the FIG definition of surveying.

The FIG definition addresses mainly discipline specific tasks. The body of knowledge may require additional knowledge and skills such as communication, leadership, business management, public policies, public administration etc. A professional person is not only a technically and scientifically savvy individual but also someone that functions in the world around him. This latter knowledge and skills will be addressed in the macro level body of knowledge.

THE MACRO LEVEL BODY OF KNOWLEDGE

Before describing the macro level body of knowledge it is beneficial to examine what does a surveyor do from a different perspective. A more general view of surveying can be adopted from Chrisman definition of GIS (Chrisman 2002). Chrisman defines GIS as:

The organized activity by which people:

- ***measure** aspects of geographic phenomena and processes;*
- ***represent** these measurements, usually in the form of a computer database, to emphasize spatial themes, entities, and relationships;*
- ***operate** upon these representations to produce more measurements and to discover new relationships by integrating disparate sources; and*
- ***transform** these representations to conform to other frameworks of entities and relationships.*

Chrisman extends this definition by adding to it the social, cultural and institutional contexts in which GIS professionals operates. This is described in figure 1. One can easily adopt this as a general definition of surveying. Thus, the surveying body of knowledge should not only address the mathematical, physical, technical, legal, etc., aspect of surveying but be broader to include general knowledge that can be used in the outer bands of figure 1.

It is also important to view the role of the surveyor from a broader perspective. The role of a surveyor is not necessarily to perform all the technical field and office work. This could be done by technicians who work under the supervision of a licensed surveyor. It is common practice in most professions that aids and technicians perform routine tasks and the professional person is involved only in the higher level aspects of the work. Professionals are involved in problem definition, scope, methodology, means, analysis, creativity, synthesizing alternatives, iteration, regulations, codes and safety not in technician level work. Such a view of the role of the professional surveyor will elevate the surveying profession into a higher and more prestigious status.

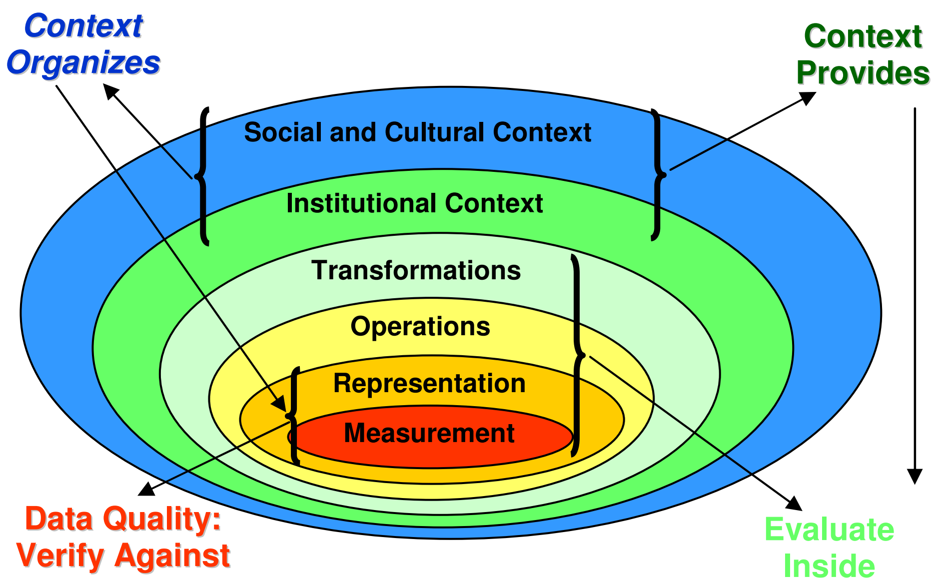

Figure 1. The definition of GIS based on Chrisman (Chrisman 2002)

In order to enable the future surveyor to become the professional just described and to master new technologies and advanced data processing methodologies, and to be respected by the public, he/she should have as a minimum the following knowledge base and skills:

- A technical core of knowledge and breadth of coverage in mathematics, science, and technology.
    - The knowledge in mathematics must be beyond algebra and trig. Calculus and linear algebra must be included in order to understand error theory and least squares (LS) adjustment. As surveying technology evolves, redundant

observations are easier to obtain. Redundant observations are the most important vehicle to supervise, monitor and assess the quality of work done by technicians.
    - The knowledge in statistics includes statistical testing and blunder detection theory. As before this is an indispensable means for QC/QA
    - Computer science
    - Knowledge in physics and other science is important in order to understand how modern surveying tools work. Understanding how the equipment works will make it easier to understand how to work with the equipment, and how to minimize and evaluate possible error. This will distinguish the surveyor from "GPS made everyone a surveyor"
    - Information science and information technology especially as it relates to geo-spatial information. Almost all a surveyor does is related to spatial information systems.
    - Basic knowledge of the science behind Geodesy (ellipsoids, geoids, map projections, geometric representation of the earth, height systems, gravity), image and sensor based mapping systems (terrestrial, air or space borne).

- Law, ethics and professionalism
    - A surveyor needs to have a broad knowledge of the law beyond the obvious, namely, boundary law. The knowledge should include elements of the legislative process, courts and the court system, statuary law, administrative law, the legal process, real estate law, business law, legal forms of ownership, etc. This will help the surveyor to be familiar with framework in which he/she functions.
    - The surveyor is to hold paramount the welfare of the public. A surveyor needs to demonstrate an understanding of and a commitment to practice according to the fundamental principles of ethics and the codes of professional conduct.

- Communication, history, social science and contemporary issues
    - A surveyor needs to be versatile with communication and presentation tools such as word processing, spreadsheets, slide presentations, graphics, visualization, the worldwide web and others to present himself in a professional manner.
    - To be effective, a surveyor should appreciate the relationship of surveying to critical contemporary issues such as the technical, environmental, societal, political, legal, economic, and financial implications of surveying and spatial information projects.

- Business, economics, management
    - This knowledge is needed because a surveyor commonly runs his/her own business or a surveying department in a larger consulting firm or in a surveying department in a public company or in local government. It is also needed because a contemporary surveyor should be able to manage projects,

contracts, people, budgets, schedules, finance, marketing and sales, billable time, overhead, profits, etc.

- At least one in-depth specialty in surveying law, geodesy, GIS, image based mapping, or other.

This could be summarized using the outcome evaluation format of ABET. The summary is presented in table 2. ABET mandates items 'a' through 'k' and encourages adding discipline specific outcomes. Items 'l' through 'o' are surveying specific outcomes that were added to the ABET mandatory outcomes.

Figure 2 summarizes the macro level surveying body of knowledge. It lists the core knowledge with specific technical and scientific knowledge areas shown in the center of the figure. However, this core knowledge should be supported by other knowledge areas to define the profession in the real world context. In an analogy taken from the surveying practice one can say that the core knowledge is creating a map with assumed coordinates and by adding to it the general knowledge we georeference the surveying profession into the rest of the world.

a. **an ability to** apply knowledge **of mathematics, science and engineering/applied science/technology.**
b. an ability to design and conduct **experiments,** as well as **analyze** and **interpret** data.
c. an ability to **design** a system, component, or process to meet desired needs.
d. an ability to function on **multi-disciplinary teams.**
e. an ability to identify, formulate and solve **Surveying (engineering) problems.**
f. an understanding of **professional and ethical responsibility.**
g. an ability to **communicate** effectively.
h. a broad education necessary to understand the **impact of Surveying (engineering) solutions** in a global and societal context.
i. a recognition of the need for, and an ability to engage in, **life-long learning.**
j. a knowledge of **contemporary issues.**
k. an ability to use the techniques, skills, and modern **Surveying (engineering) tools** necessary for surveying (engineering) practice.
l. an ability to apply knowledge in a **specialized area related to Surveying.**
m. an understanding of the elements of **supervision and project management.**
n. an understanding of **business and public policy and administration fundamentals.**
o. an understanding of the **role of the leader** and **leadership principles.**

Table 1. 15 outcomes that are to be met by the surveying body of knowledge.

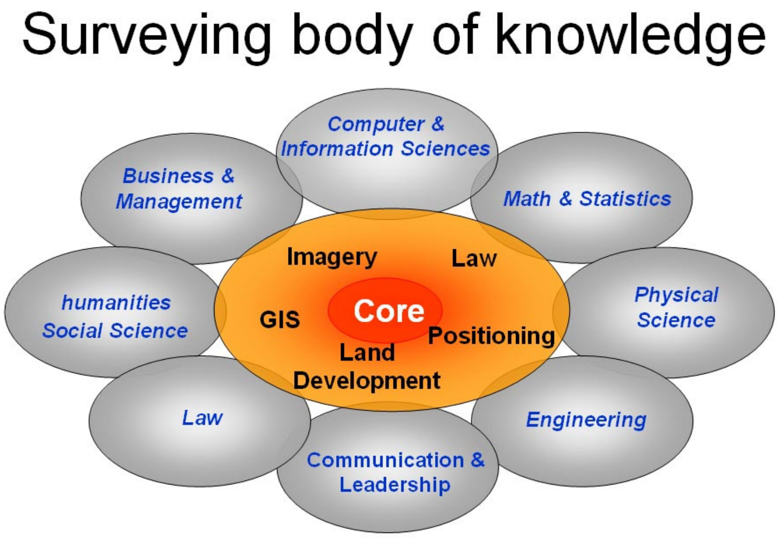

Figure 2. The comprehensive macro level surveying body of knowledge.

THE MICRO LEVEL BODY OF KNOWLEDGE (GIS EXAMPLE)

As mentioned earlier, the body of knowledge can be defined in a general (macro) level and more specific (micro) levels. The ACSM committee is currently working on developing draft subsets of bodies of knowledge for surveying in the areas of positioning, imagery, law, GIS and land development. An example of what is being developed is herein demonstrated by the GIS body of knowledge subset. Some of the material presented in this section was adopted from [AAG 2006]

The first task is to define the role of surveyors in GIS and the role of GIS in surveying. This is a critical and challenging task. As mentioned earlier Chrisman's definition of GIS [Chrisman 2002] can be interpreted also as the definition of surveying because one can claim that it describes what surveyors do. Similarly, items 6 and 7 in FIG's definition of surveying shown in table 1, include almost the entire spectrum of GIS. Yet, a case can be made that not every surveyor has to know everything about GIS. On the other hand every surveyor has to have a minimum knowledge of GIS. Therefore, it is reasonable to establish the GIS knowledge base as a function of the surveyors' level of involvement or specialization in GIS. Marble (Marble 1998) suggests six roles played by GIS&T professionals. The six levels (from the least intensive knowledge to the most) are:

1. Basic spatial and computer understanding
2. Routine use of basic GIS technology
3. Higher level modeling application
4. GIS application design and development
5. GIS system design
6. GIS research and software development

This is a quite detailed list which is not really necessary for our goal. Therefore, when applying Marble's levels to surveying they can be reduced to 3 categories of involvement. The suggested 3 categories are:

1. User — Routine use of basic GIS technology
2. Specialist — GIS application design and development
3. Scholar — GIS research and development

The minimal level of GIS knowledge a surveyor must master should enable him/her to routinely use basic GIS technology. This includes not only the ability to retrieve and display spatial data but the ability to perform data manipulations (data conflation, projections, etc.) and the ability to deliver to their clients surveying findings in a GIS format. The next level of surveyors' role in GIS is termed as GIS specialist. A GIS specialist in this context is a surveyor whose main professional practice focus is in GIS. This would normally entail developing and maintaining GIS applications on a regular basis. A GIS specialist is a surveyor who is able to perform the entire design and implementation processes from start to finish and understand the context for which that GIS system exists. Other duties performed by a GIS specialist could include maintenance of enterprise GIS systems, adaptation of new technologies and migration of the system to new conceptual models. For example, migration from a relational database concept to object oriented database concepts.

The highest level of a surveyors' role in GIS is termed as GIS scholar. GIS scholars are surveyors whose main professional objective is to developed solutions for surveying (or surveying related) problems with GIS concepts. For example, reconciling deed conflicts to create a seamless parcel layer or create a dynamic GIS application for points affected by crustal motion. The role of GIS scholar should place the surveying profession in the forefront of GIS science research and development. There is no reason why individuals with a surveying expertise should not be involved in shaping the future of GIS knowledge and technology.

LEVELS OF COMPETENCIES

Each of three involvement categories will require not only different breath of GIS knowledge but also different depth of knowledge. There are several ways to define depth of acquired knowledge. Anderson and Krathwohl (Anderson & Krathwohl, 2001) suggest six levels of acquired knowledge and competence:

- **Remembering**: Retrieving, recognizing, and recalling relevant knowledge from long-term memory.
- **Understanding**: Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.
- **Applying**: Carrying out or using a procedure through executing, or implementing.
- **Analyzing**: Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.
- **Evaluating**: Making judgments based on criteria and standards through checking and critiquing.
- **Creating**: Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.

Greenfeld (et. al, 2008) suggests a simplified three level of knowledge and competence depth that is used for the macro level surveying body of knowledge. The three levels of competence are:

- Level 1 (***Recognition***) represents a reasonable level of familiarity with a concept. At this level, the surveyor is familiar with a concept, but lacks the knowledge to specify and procure solutions without additional expertise. For example, a surveyor might *recognize* that a particular GIS project poses significant implementation challenges without having the expertise to devise improved implementation or design alternatives.

- Level 2 (***Understanding***) implies a thorough mental grasp and comprehension of a concept or topic. Understanding typically requires more than abstract knowledge. For example, a surveyor with an *understanding* of boundary law should be able to identify and to communicate legal issues arising from a practical case study.

- Level 3 (**Ability**) is a capability to perform with competence.

These three levels of depth of knowledge and competencies are used to construct the GIS body of knowledge for surveying. The body of knowledge has 3 categories, namely, user, specialist and scholar. Table 3 summarizes the GIS&T knowledge areas and units [AAG 2006] and provides a suggested level of competency for each involvement category.

GIS Knowledge	user	specialist	scholar
Knowledge Area: Analytical Methods (AM)			
Query operations and query languages	U	A	A
Geometric measures	A	A	A
Basic analytical operations	A	A	A
Basic analytical methods	A	A	A
Analysis of surfaces	A	A	A
Spatial statistics	U	U	A
Geostatistics	R	U	A
Spatial regression and econometrics	R	R	R
Data mining		R	U
Network analysis		U	U
Optimization and location-allocation modeling		R	A
Knowledge Area: Conceptual Foundations (CF)			
Philosophical foundations	U	U	A
Cognitive and social foundations	R	U	R
Domains of geographic information	U	A	A
Elements of geographic information	A	A	A
Relationships	U	A	A
Imperfections in geographic information	U	A	A
Knowledge Area: Cartography and Visualization (CV)			
History and trends	A	A	A
Data considerations	U	A	A

GIS Knowledge	user	specialist	scholar
Principles of map design	A	A	A
Graphic representation techniques	A	A	A
Map production	U	A	U
Map use and evaluation	A	A	A

Knowledge Area: Design Aspects (DA)

The scope of GIS&T system design	U	A	A
Project definition	R	A	A
Resource planning	R	A	A
Database design	R	A	A
Analysis design		A	A
Application design		A	A
System implementation		A	A

Knowledge Area: Data Modeling (DM)

Basic storage and retrieval structures	A	A	A
Database management systems	U	A	A
Tessellation data models	R	U	A
Vector and object data models	A	A	A
Modeling 3D, temporal, and uncertain phenomena	R	U	A

Knowledge Area: Data Manipulation (DN)

Representation transformation	A	A	A
Generalization and aggregation	R	U	A
Transaction management of geospatial data	R	A	A

Knowledge Area: Geocomputation (GC)

Emergence of geocomputation	R	U	A
Computational aspects and neurocomputing			A
Cellular Automata (CA) models			A
Heuristics			A
Genetic algorithms (GA)			A
Agent-based models			A
Simulation modeling			A
Uncertainty		R	A
Fuzzy sets			A

Knowledge Area: Geospatial Data (GD)

Earth geometry	A	A	A
Land partitioning systems	A	A	A
Georeferencing systems	A	A	A
Datums	A	A	A
Map projections	A	A	A
Data quality	A	A	A
Land surveying and GPS	A	A	A
Digitizing	A	A	A
Field data collection	A	A	A
Aerial imaging and photogrammetry	A	A	A
Satellite and shipboard remote sensing	A	A	A
Metadata, standards, and infrastructures	U	A	A

Knowledge Area: GIS&T and Society (GS)

Legal aspects	A	A	U
Economic aspects	R	U	U
Use of geospatial information in the public sector	R	U	U
Geospatial information as property	A	A	U

GIS Knowledge	user	specialist	scholar
Dissemination of geospatial information	U	A	U
Ethical aspects of geospatial information and technology	R	A	U
Critical GIS			U
Knowledge Area: Organizational and Institutional Aspects (OI)			
Origins of GIS&T	R	U	U
Managing GIS operations and infrastructure	R	A	U
Organizational structures and procedures		A	U
GIS&T workforce themes		U	R
Institutional and inter-institutional aspects		A	R
Coordinating organizations (national and international)		A	

Table 3. GIS&T knowledge areas and units and a suggested level of competency for GIS users, specialists and scholars (bold types mean core requirement).

A similar approach for the micro level surveying body of knowledge is currently under development in the areas of positioning, imagery, law and land development. It is important to note that the above is a proposed approach for determining the GIS body of knowledge and it will be finalized following a comprehensive review by members of the surveying community.

GIS EDUCATION FOR SURVEYORS

One persistent challenge for the surveying profession in the US is the lack of mandatory college education for licensure across the nation. Experience gained under a licensed surveyor for any length of time will not enable the surveyor to acquire the minimum GIS body of knowledge as outlined above. It is reasonable to expect that curriculums in all four year degree surveying programs will enable their graduates to become at least a competent routine user of GIS. Graduates from a typical surveying program who take additional GIS classes or graduates from surveying programs with GIS concentration could become GIS specialists. To become a GIS scholar it is anticipated that an advanced degree would be required. The advanced degree would preferably (but not necessarily) be in surveying/geomatics or in another related discipline. One can also become a GIS scholar with surveying specialization by earning a related or unrelated undergraduate degree (e.g. science, math, and engineering) and an advanced degree in a surveying/geomatics program. The educational requirements for the three roles of surveyors in GIS are shown in table 4. ***R*** indicates that the education is required and ***P*** (plus) indicates that it is preferable to have that additional education.

	Under-graduate degree	Professional Education	Post baccalaureate Certification	Graduate degree
Routine user	***R***	***R***	***P***	**-**
Specialist	***R***	***R***	***R***	***P***
Scholar	***R***	***P***	***P***	***R***

Table 4. GIS Educational requirements for surveyors. R-Requires, P-Plus

SUMMARY AND CONCLUSIONS

A profession is founded on knowledge, skills and education. An important aspect of a profession is the body of knowledge that defines it. The body of knowledge for a given profession can be developed on a macro level or on a micro level or both. Developing both levels of bodies of knowledge has the advantage of defining not only the contemporary needs of the profession but also the long range, technology independent lifelong body of knowledge. In this paper an attempt was made to draft a format for both levels of the body of knowledge. They were based on previous work done by closely related professions, namely, Civil Engineering and GIS.

The macro level surveying body of knowledge was outlined not only by describing the core technical/scientific knowledge base of surveying but also keeping in mind the role of a professional person in today's world. In the micro level example of the surveyors GIS body of knowledge the necessary competencies and levels of knowledge were divided into categories as a function of specialization. No one person is capable of knowing everything in all knowledge areas. Therefore, a minimum level of knowledge was defined and additional required mastery of knowledge was defined for more involved roles in the specific subset of the knowledge base. Finally, the level of education for acquiring the different levels of knowledge and skills were outlined as well.

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CONTACTS

Professor Joshua Greenfeld, PhD., LS
Professor emeritus, NJIT
Professor, Israel Institute of Technology
greenfeld@njit.edu