On the Design of a Multidisciplinary Remote Sensing Graduate Course

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Abstract – The field of remote sensing involves the acquisition, processing, and analysis of information acquired using many different measurement modalities over many environments, as well as decision making based upon that analysis. It is therefore inherently multidisciplinary. Professional societies, such as the Institute of Electrical and Electronics Engineers (IEEE) and the American Geophysical Union (AGU), recognize this and provide venues (symposia and archival literature) for research on remote sensing topics by both engineers and scientists. Unfortunately, the curricula for remote sensing at many universities are *ad hoc* collections of discipline-specific courses that provide little generality or continuity. At the University of Florida, we are attempting to address the need for a generalized remote sensing education through the introduction of a Geosensing Systems Engineering graduate degree program. One of the courses in this new degree program is a class on sensor phenomenology and data analysis. The goal of the class is to introduce the students to rigorous mathematical methods that are sufficiently general to be applicable to virtually any data set, rather than to dwell on specific applications. In its first offering during the spring of 2004, students enrolled in this class represented five different departments and two different colleges.

Keywords: graduate curricula, multidisciplinary education, remote sensing.

I. Introduction

The report by The Boyer Commission on Educating Undergraduates in the Research University [1] concluded that, "Unfortunately, research universities are often archipelagos of intellectual pursuit rather than connected and integrated communities." The disconnection described in [1] stifles the great potential synergy between engineering and science departments, such as Earth science and medicine, on university campuses. Curricula that explore the intersection between engineering and Earth science, for example, can provide many opportunities for students to build connections between these disciplines.

There has been much discussion in recent years regarding the need for a more integrated approach to research in various fields. One hears the terms "interdisciplinary" and "multidisciplinary" (MD) repeatedly. However, deciding how to realize the potential benefits of integrated research education requires planning. A MD approach is particularly well suited for application-driven endeavors, such as remote sensing (RS). RS is concerned with measuring objects and processes from large distances and interpreting those measurements for Earth science research and applications, such as mitigation of natural hazards. The case for interdisciplinary research in the geosciences is presented in [2]. The authors predict increased collaboration and significant fading of boundaries among geoscience disciplines over the next 20 to 30 years as a natural consequence of the magnitude and multi-faceted nature, both scientific and societal, of problems that require input from the geoscience community. The

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mitigation and possible modification of many natural hazard processes is predicted to lead to significant cooperation between disciplines. A recent example of this is the study of the recent tsunami that resulted from a submarine earthquake in the Indian Ocean. Seismologists studied the crustal motion and geodesists estimated the resulting perturbing of Earth's rotation. The merging depicted in Figure 1, from [2], should be considered to represent increased inter-connecting of research communities, rather than a complete merging, so the disciplines may address scientific problems in a coordinated way while leveraging off of expertise in their sibling disciplines. Some differentiation and specialization will certainly remain in all fields. However, the authors also point out that there is a need to develop infrastructure for better communication between Earth scientists and engineers. The graduate course described in this work is an attempt to realize a more integrated curriculum that serves both Earth scientists and engineers. The course strives to promote research that remains firmly grounded in the methods of electrical engineering while exploring applications in environmental remote sensing.

II. Parts of a whole

The potential to realize MD education in a large research university setting is high because many cross-cutting disciplines are represented in a single institution. The topic of RS is a natural vehicle for multidisciplinary research because a complete treatment requires contributions from both engineering and scientific literature. Unfortunately, the implied teaming between engineers and scientists usually does not occur until students graduate and find themselves working in MD groups in government labs or industry. Fostering such teaming in academia will prepare the students to be successful in such environments after graduation.

The University of Florida (UF) is an example of a large state university where many different engineering and scientific disciplines are represented. There are many groups at UF engaged in RS research, including the Geosensing program in the Department of Civil and Coastal Engineering [3]; the Center for Remote Sensing in the Department of Agricultural and Biological Engineering [4]; several in the Institute of Food and Agricultural Sciences (IFAS), including the Range Science Geospatial Lab [5], GIS and Remote Sensing Laboratory in the School of Forestry [6], Precision Agriculture and Remote Sensing Group [7], and the Geomatics degree program [8]; and courses taught in the Geography Department [9]. These activities are hosted in different departments and colleges and range from individual courses to research groups. Unfortunately, most of these efforts are not coordinated with each other, and in some cases, are not even aware of each other. For MD RS research to thrive and realize the potential synergy from cross-cutting efforts, these components should be viewed as parts of a whole. In Figure 2, a hypothetical linkage is depicted between MD curricula and research. Connecting and synchronizing the Curricula and Research rails of MD scholarship would reinforce a cycle of recruiting and graduating high quality students that would be well prepared to contribute and lead MD research in industry, government, and academia.

At UF, a Geosensing Systems Engineering (GSE) graduate program was recently established [3] to better align the curriculum to ongoing research activities for RS. The GSE program is in the Department of Civil & Coastal Engineering and was first available for students admitted in 2004. The program is intended as a Ph.D. degree program, but does have a M.S. degree option. A fixed set of core classes is taken in the first three semesters and then followed by selected courses from several departments. A summary listing of pre-approved electives is given in Table 1. Students can choose courses from a list of pre-approved electives, and they can also choose other classes with advisor and department approval. While curricula with significant elective components may not be uncommon on smaller universities or colleges, they are generally rare at large universities. Since several out-of-department courses are part of the GSE curriculum, a large and diverse collection of approved electives is critical since the host department does not generally have control over when and how often classes in other departments are offered. Thus, the curriculum must be sufficiently flexible to accommodate this.

With this approach a single department can construct the curriculum because specific degree requirements of the elective course departments need not be met. The particular course described in this work is titled *Remote Sensing Phenomenology and Data Analysis*. It has been taught once to date and is scheduled to be taught once per year. It is one of the core courses for students enrolled in the GSE program, and students from other departments can take it as one of their out-of-department courses. The GSE program is weighted more towards engineering topics rather than purely scientific topics since it is hosted in an engineering department, but many science applications are presented and discussed in class and in the homework. An analogous class hosted in a science department could certainly be designed with a similar overall structure that gave more emphasis to the science topics. While a MD graduate curriculum should be inclusive, pragmatic considerations in most academic institutions make it likely that it will be hosted by one department. That department will desire that the program meet its requirements and serve its students. Thus, there will be some coloring of the program curriculum based on the department to which it belongs. In the GSE program for example, the core courses are designed to serve this purpose, which frees up the approved electives to be broadly defined.

Table 1. Summary of GSE curricula at UF

Core courser work	***Selected Topics***
Civil & Coastal Engineering	Mapping adjustments, Geodesy, Instrumentation, GPS methods, Laser mapping, Digital mapping
Approved electives:	
Electrical & Computer Engineering	Digital signal processing, Pattern recognition, Stochastic processes, Photonics
Computer & Information Sciences & Engineering	Computer vision
Agricultural & Biological Engineering	Remote sensing for hydrology, Passive microwave remote sensing
Urban & Regional Planning	Survey planning, Advanced planning
Astronomy	Astrophysics
Mathematics	Linear algebra
Geological Sciences	Coastal morphology

III. Course Philosophy

Broad-based topics like RS are natural conduits for MD education, but the degree to which a single course can coordinate with other RS efforts at a school depends on the particular course offerings at that school. The course should be self-contained so that it can exist on its own, but it can certainly “link up” with other courses to the extent that potential follow on courses, such as image processing, electromagnetics, physical geography, or geomorphology, are discussed in class. Only a small subset of these follow on courses will be of serious interest to any one student, but cumulatively they form a network of RS education that achieves breadth and depth.

The RS class described in this work is a gateway to this network, but what are some of the barriers to such a network? The first may be in creating a class with sufficient content in a single field that the host department agrees to create it, generally as a “special topics” course initially. Once it is created, students must be recruited to take it, especially if few related courses already exist in the host department. Recruiting students is a two-part process that must address (1) potential prerequisite barriers and (2) risk-to-reward ratio as perceived by the perspective student. Firstly, selected topics must be covered in sufficient depth to teach the students useful skills and not have a watered down survey course. In traditional mono-disciplinary courses, this is handled by requiring prerequisites to ensure a certain level of proficiency on selected topics. But if the class is to consist of students from different departments and colleges, it is generally not feasible to impose any prerequisites since curricula vary so much across departments. Differences between electrical engineering and computer science curricula may not pose a problem, but differences between electrical engineering and biology probably will.

A list of suggested prerequisites in the course syllabus can be helpful, but it is best to only require graduate standing. In the course, the students will be able to choose projects that correspond to their backgrounds and thus go very deeply into a given subject. As long as that research deals with the selection, processing, and/or analysis of RS data, the instructor can teach the student a great deal no matter what discipline the project application belongs to. An alternative approach would be to have multiple MD courses that are taught in a sequence. Generally, this will be constrained by the limited number of out-of-department courses students not in the host department can take and have count towards their degrees. Certainly, the more departments collaborating on integrated curricula, the more the prerequisite issues recede.

How does one successfully attract students with multiple backgrounds to such a class? Possible backgrounds include stochastic processes, signal/image processing, machine learning, hydrology, geology, geography, biology, and forest ecology. One factor is to avoid in-class exams or at least not to weight them heavily. The target audience of graduate students from different departments will not be eager to take in-class exams in an area they are not expert in. This policy should be stated clearly on a course flyer and syllabus available on the Web. Graduate coordinators in various departments can be asked to advertise the class in their departments via email.

IV. Course Structure

The *Remote Sensing Phenomenology and Data Analysis* course was first taught in 2004 and is intended to be taught once per year as part of the core curriculum in the GSE graduate program, which was created in 2004. Several factors must be considered when structuring a graduate-level MD course. What is the target audience? What should the primary pedagogical modalities be? What is an appropriate grading policy? What reference material and/or software tools should be used? What is the performance metric for success? To be effective, the course must cover the right content at the right depth and teach the students to teach themselves (i.e. become independent researchers) [10]. The primary activities of the course include lecturing, individual work on homeworks and take-home exams, and team work on projects. These activities reinforce each other. Lectures represent knowledge transfer from the instructor to the student. So the lectures on each topic should start from an intuitive motivation and then move into the detailed mathematics or physics. As the students work on team assignments, they interact with each other. An appreciation for each others' disciplines develops along with synergistic learning. In this activity, the flow of knowledge is from student to student. Finally, the students work on individual assignments, such as homeworks and exams. In this case, the demonstration of knowledge is from the student to the instructor and individual student performance is easily measured. Areas where student understanding is weak can be quickly identified.

Target Audience

What should the target audience for such a course be? The ideal out-of-department audience is composed of graduate students that have already completed at least one year of course work. This makes it more likely that they are proficient in at least some forms of analysis for their particular discipline, be it signal processing or biological process modeling. Ideally, they will be Ph.D. students that have taken their qualifiers and are starting to think about research for their dissertations or MS students working on their theses. Many of the students that have completed a year or more of graduate school will come to the course with their own data and research projects from the research assistantships. They will primarily want help with analysis methods. Others will not have data of their own and will be more curious about entering RS as a field. These students should be encouraged since this is a chance to excite them about multidisciplinary research and, in this case, remote sensing.

Pedagogical Modalities

The same pedagogical modalities that promote good learning in a traditional class hold for a MD class. For example, Piaget's proposition of individuals constructing their own knowledge has led to a learning theory based on constructivism from which a *scientific learning cycle* (see Figure 3) can be derived [11]. Incorporating pedagogical elements, such as presenting complex mathematical or physical ideas graphically and through symbolic and numeric examples is critical. In a first class on a broad-based topic, such as RS, it is particularly important to introduce the myriad of technical terms that appear in the literature so that students do not get lost in the vocabulary. When these elements are put in place, they indeed form a cycle of learning with each element reinforcing the others.

Aside from theories of multi-modal learning, there is a common sense reason to employ a good mix of theory (pencil and paper) and applications (coding and real data). In Figure 4, examples are shown of how the concept of calculating the laser light reflected from forested terrain can be depicted using physical models, theoretical (symbolic) mathematics, and numerical representations. Students from disparate backgrounds will not necessarily have equal skill or familiarity with these different representations. Fairly evaluating their performance requires that every effort be made to help them attain minimum levels of understanding and proficiency to analyze data and interpret results. Topics like RS are ideally suited to MD approaches because they are broad. Yet that same quality makes it difficult for any single individual to get up the learning curve and become literate in the field. For example, one student may know a great deal about signal processing, but have no notion of how to quantify geomorphologic landforms or processes. The names of instrument classes, such as radiometer, scatterometer, radar and lidar, can easily be confused by the student with specific program and mission names, such as EOS, Terra, Aqua, and MODIS. For this type of information, prepared notes distributed to the students and projected during lecture work well. Later in the course, when analysis methods and theories are covered, traditional lectures and writing on the board work well.

Topical Organization and Course Objectives

The course topics on remote sensing and data analysis are arranged into halves and listed in the course syllabus [12]. The first half pertains to different sensor classes, how they work, and the physics of electromagnetic interactions between the incident energy and the terrain. It also covers the basic processing (e.g. geometric and radiometric corrections, calibration) that must often be applied to RS data before it can be properly interpreted. The last half covers several methods of analyzing data, such as inner product transformations (Fourier, wavelet, Karhunen-Loève), filtering, statistical estimators, and multiscale data fusion. This organization was found to work reasonably well during the initial offering of the course. However, in subsequent offerings, a greater percentage of the preliminary information on sensors and technologies will be distributed as handouts so that more time can be devoted to the analysis portion of the course material. Another lesson learned from the first offering is that more structure should be imposed on the choice of project topics and methods to ensure a sufficient level of rigor from all students regardless of background.

Homework and project assignments in the class are sequenced to correspond both to the topical organization and to a natural ordering of key educational objectives. Four main objectives are derived from five of the major cognitive domain components, as classified by Bloom, et al. [13].

(1) *Knowledge*. The first cognitive domain component is knowledge, which is comprised of definitions, technical terms, and facts. In RS, many different sensors have been deployed by various governmental agencies under a myriad of programs. The result is a confusing array of acronyms and terms that act as a barrier to students trying to enter the field. The first homework assignment is therefore focused on getting the students to research, catalog, and classify various groups of sensors and sensing programs. The object is to have the students document the majority of sensors and data types available.

(2) *Comprehension*. Knowledge of the sensors and available data types is necessary for the students to progress to the next educational objective, which is to describe what sensor technologies one would use to observe particular Earth system processes or states, such as land subsidence. This objective requires comprehension of how the pertinent physical characteristics of processes or states of nature drive what sensor technologies are best suited to observe the process or state. Students demonstrate their comprehension in the second homework assignment and in a pre-proposal (white paper) for their project idea, in which they must determine what technologies are needed to study a particular process.

(3) *Application*. As the lecture material moves into more mathematical treatments of data from different sensors, the application of abstract concepts, such as applying Fourier analysis to reduce noise in the data or affine transformations to align images to one another, occurs. The primary objective in the third homework and in the full project proposal is for the students to numerically analyze some preliminary data to demonstrate that the approach they have chosen to investigate the problem statement or scientific hypothesis posed in their project proposal is a reasonable one.

(4) *Analysis* and *Synthesis*. Finally, the lecture material covers methods for analyzing measurements and inferring properties of the observed physical processes from the data. This endeavor involves two classes in Bloom's taxonomy, analysis and synthesis. Methods such as maximum likelihood estimation of the probability of the observed process corresponding to a particular state of nature are studied, along with recursive multiscale data fusion methods. In the fourth homework and project final report, students must be able to clearly demonstrate the use of mathematical methods to analyze the data and then make probabilistic inferences to synthesize information contributed from multiple sources.

Book and Other References

Choosing reference material, such as a textbook, for a broad-based MD course can be difficult. If the instructor requires several books in order to cover all of the material, it will be too costly for the students. Conversely, if the instructor avoids a single book and instead supplies excerpts from several sources, he will be forced to give the students a vast amount of printed notes that will almost certainly contain notational inconsistencies and lead to disjointed narratives. It is generally best therefore to find one book that covers at least the core material of the course and supply ancillary reference notes on other topics as needed.

For this RS course, three textbooks that work well are (1) *Introduction to the Physics and Techniques of Remote Sensing* by Elachi [14], which has an excellent treatment of the relevant physics, but is slightly dated regarding the sensors, (2) *Remote Sensing of the Environment: An Earth Resource Perspective* by Jensen [15], which has many good descriptions of sensors and bio/geo-physical topics, but does not treat advanced analysis methods, and (3) *Remote Sensing Digital Image Analysis: An Introduction* by Richards and Jia [16], which considers advanced analysis methods, but has little discussion of particular sensors or bio/geo-physical topics. There are several other adequate books to suit individual preferences, and this list is not intended as a recommendation.

Computer and Data Resources

Lectures are made available online to the students. For homeworks and projects, it is best to allow any computer language (e.g. C or Fortran) since some students may be familiar with only one. If available, algorithm development environments, such as Matlab, IDL, LabView, or VisiQuest, are preferable to low-level languages for rapid prototyping and debugging [17]. Most universities have computation and network offices that can provide information about the availability of such software around campus. Use of specialty software (e.g. PCI, Envi, Erdas) could be allowed for projects if the focus of the particular project is on applications rather than analysis methods. However, for homeworks or take-home exams, the point-and-click functionality of such packages may short-circuit the learning process for computer coding and algorithm creation.

In many case, publicly available RS data can be downloaded from NASA, NOAA, or other universities. Students that are far along in their own research often have their data already in hand, but the instructor should have two or three canned data sets available for students that are focusing on analysis methods and do not have a particular data set or application in mind. Also, for those students, it can helpful to tap into other groups at the university that use or build their own sensors. These groups may be eager to supply data sets for debugging purposes. It is necessary to provide instructions for downloading and viewing data from providers, such as NASA or NOAA, that often have complicated file formats. It is not practical to provide such instructions for all possible data sources so a few should be selected as examples.

Grading and Evaluation

To successfully attract students from many different departments, rigorous in-class examinations should be avoided. Most second and third year graduate students are not eager to register for extremely difficult courses outside of the home departments since they have already satisfied most of their course requirements. Class projects provide a vehicle for students with different backgrounds to use and demonstrate their particular knowledge and they also provide opportunities for MD teaming. In particular, multi-part projects encourage the students to develop their research plans early in the semester. This can be achieved by requiring initial white papers (pre-proposals) that sketch out the project idea. These can be followed by full proposals and final reports, with instructor feedback at each stage. This structure has the added benefit of teaching the students about the grant proposal writing process. However, the advantages of project assignments should be balanced by more traditional assignments so that the course can maintain sufficient rigor. Homeworks and take-home exams provide a common set of problems to work and so can promote consistent and fair evaluation of student performance across the class.

After the first offering of this course, students gave an average rating well above department and college averages when asked to assess their learning experience in the course evaluation survey. One student reported on a survey that, "I have taken six courses related to remote sensing and this is the best one by far." Another student responded to the survey question, "Do you believe this course should be offered?", by stating "Absolutely. It is the perfect primer for remote sensing topics. Its cross-discipline target was maintained throughout the semester, providing useful information and insight into the underlying mathematical principles without alienating non-specialized students."

IV. CONCLUSIONS

A multidisciplinary graduate course titled *Remote Sensing Phenomenology and Data Analysis* was developed one year ago and has been taught once. It resides in the Department of Civil & Coastal Engineering, but is cross listed in the Department of Electrical & Computer Engineering. It aims to introduce students from many different departments in science and engineering to RS concepts and applications. However, the characteristics of the course described in this work are applicable to other MD courses that could be developed for broad-based topics, such as bioengineering/medicine or geophysical exploration. Structural elements that were designed into the course are discussed, along with the reasons why they were adopted. Potential connections to graduate curricula were also presented.

Lessons learned from the first offering of this course included (1) the need to encapsulate more of the preliminary lecture material on sensors and technologies into handouts so that more time is left to cover analysis methods later in the semester; and (2) the projects should be required to explicitly employ some of the processing and analysis methods taught in class so that a sufficient level of rigor can be expected from all students regardless of their background. This course will continue to evolve each time it is taught, but it has already received good feedback from students and faculty alike.

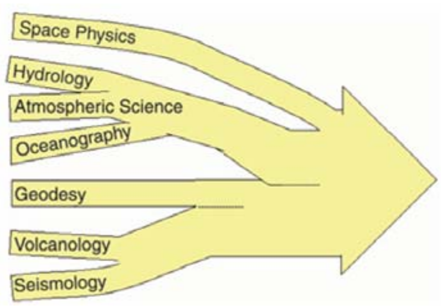

Figure 1. The anticipated merging of fields in the area of geosciences [2].

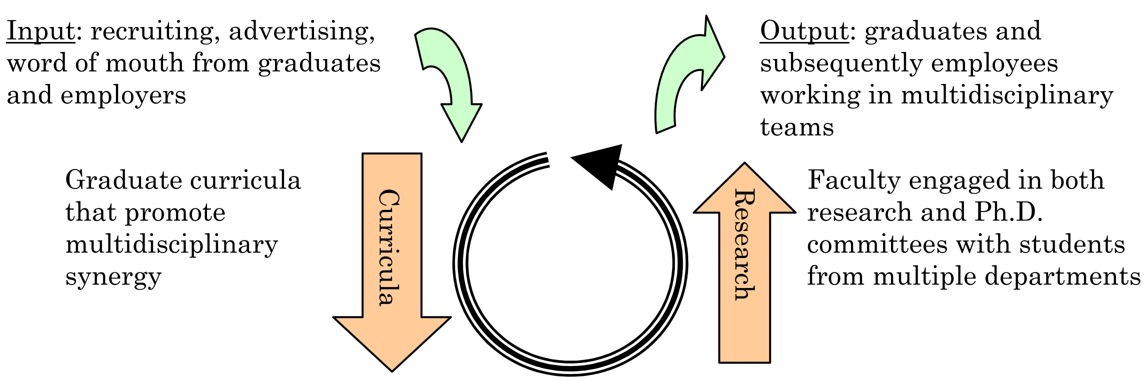

Figure 2. Programmatic level flowchart depicting how curricula and research can reinforce each other to form a cycle of strong MD scholarship at a university. The Curricula and Research rails reinforce each other.

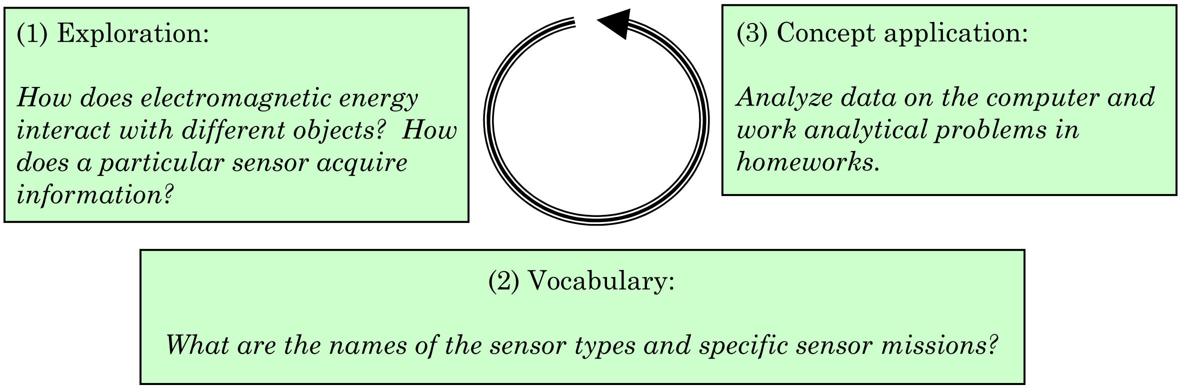

Figure 3. Scientific learning cycle based upon Piaget's constructivism theory [Wankat, 1993] (adapted for a remote sensing). The first two elements map primarily to the first half of the course, while the third element maps primarily to the last half.

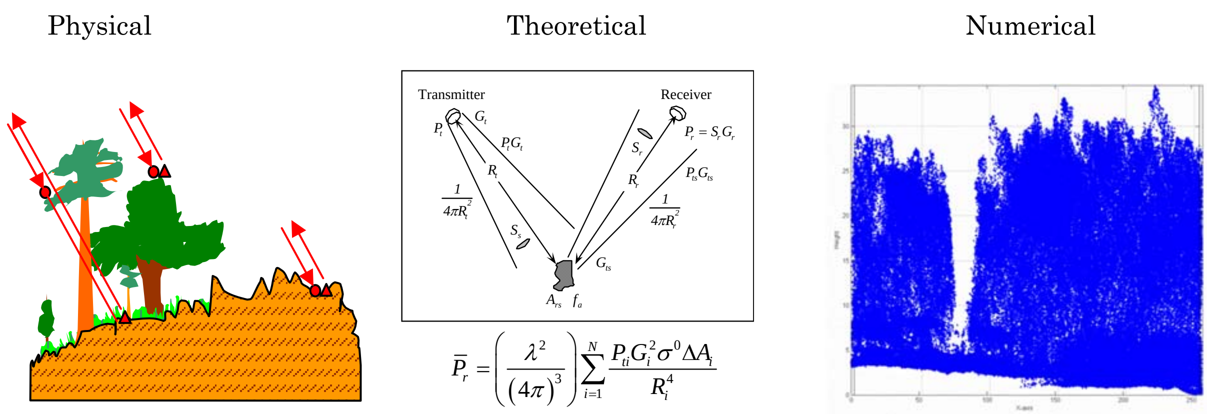

Figure 4. Examples of three primary teaching modalities for explaining how laser light reflects off of forested terrain: (left) physical modeling, (center) theoretical derivation, and (right) numerical representation.

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