PROJECT SUMMARY

The Department of Mathematics at University of Central Florida is proposing a CSUMS project. It represents a team effort of faculty members from mathematics, computer science, education and industry to introduce a year-long computational mathematics research and training program based on the successes and experiences of the team in undergraduate research in computer vision and imaging science over the past twenty years. With a year-long training program in computational mathematics using exciting applications of mathematics in images and videos as motivating examples, it is possible to provide participants with a solid background in both mathematical theory and problem solving techniques to pursue careers and graduate study in fields that require integrated strengths in computation and the mathematical sciences. The project will restructure and improve the current curriculum in computational mathematics track at UCF, making impact on a wide range of students.

Our CSUMS will have a cohort of 10 participants per year, for five years. The key distinctive elements of our approach are (1) to have a full year training in carefully designed course work so that the participants can master the mathematical and computational fundamentals, (2) to engage each participant in a meaningful research project integrated into the year-long program, (3) to present each participant with several possible project topics, so that they can feel they have chosen a project which is most interesting to them, (4) to immerse the participants in the general research environment essentially as if they were graduate students, and (5) to develop the participants' skills in communicating scientific ideas in writing and oral presentations through writing journal papers for publication, giving routine seminar presentations, and presenting at the professional meetings.

Our program starts in the spring semester with classes that prepare students in numerical methods, mathematical modeling, and computer vision and imaging science. Then, in an intensive summer component, the students immerse themselves in a research project. In the fall semester they continue to conduct research and take additional classes in advanced computer vision and imaging science, and advanced mathematical modeling. In the follow-up spring semester, the students submit their research for publication, finish an undergraduate honors thesis, and get training in graduate career advancement issues. In addition, participants will attend professional conferences, which will give them a chance to present their research and to meet known researchers in the field, who may serve as their role models. To broaden the students' perspective, there will be field trips to technology companies in the Orlando area such as Lockheed-Martin, Harris, and Boeing. Finally in order to promote interaction amongst the students and faculty, we will organize several social events including dinners with distinguished speakers visiting the campus, and parties for graduating Ph.D. students, etc.

Intellectual Merit: Development of a year-long research oriented curriculum for computational mathematics. In particular, CSUMS participants will be trained in and exposed to the latest techniques and critical issues in computational mathematics through both upgraded and newly designed courses and real life research projects in computer vision and imaging science, which involve video compression, image denoising, object detection, tracking, activity and event recognition. We believe in both theory and practice; we are interested in computation, mathematical modeling, and analysis of difficult vision problems and developing algorithms, while at the same time building real systems for demonstrating those solutions in real life situations.

Broader Impacts: This project will contribute to preparing a work force of diverse scientists in order to maintain America's previously-held strategic position of command in Science and Engineering. Participants will be trained in Computational Mathematics with an emphasis on computer vision and imaging science, in particular they will learn fundamentals of computation with applications that impact in areas such as national defense and intelligence, homeland security, and biomedical and life sciences. The proposed CSUMS model, its evaluation, and research and curriculum materials will be disseminated to other colleges and universities via a dedicated web site.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

	Total No. of Pages	Page No.* (Optional)*
Cover Sheet for Proposal to the National Science Foundation		
Project Summary (not to exceed 1 page)	1	
Table of Contents	1	
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	15	
References Cited	6	
Biographical Sketches (Not to exceed 2 pages each)	18	
Budget (Plus up to 3 pages of budget justification)	13	
Current and Pending Support	14	
Facilities, Equipment and Other Resources	1	
Special Information/Supplementary Documentation	2	
Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1 Overview

The objective of this CSUMS proposal is to develop a rigorous one-year enhanced research experience in computational theory and practice for undergraduate mathematics majors through carefully designed course work and guided research projects and activities. We envision that, after the year-long training program, our students will be ready to pursue careers and graduate study in fields that require integrated strengths in computation and the mathematical sciences. Our confidence is built on the extensive experience of the PIs and senior personnel in successfully directing a large number of undergraduates research for almost two decades [2], advising undergraduate Honors in the Major theses, developing and teaching interdisciplinary honors seminars, and the dedicated, interdisciplinary team work spirit that pervades our group. In addition, it is a common myth in math undergraduate circles, that their field is not applied to real-world problems. To clearly dispel this misconception, our team includes Dr. Muise from industry, who will actively demonstrate the life of a real-world practicing industrial mathematician. Dr. Muise is a mathematician, working at defense contractor Lockheed-Martin.

Why Computer Vision and Imaging Science? Computer vision and imaging science are ideal for illustrating to mathematics majors the issues in computational science because their applications are intuitive and visual. They provide a suitable platform for undergraduate students to see how sophisticated computational mathematics works in offering and improving solutions to real world problems.

In addition to the pedagogical reasons, as an important area of computational sciences, computer vision, and imaging science in general, demands new computational mathematics and algorithms to deal with the ever growing need of intelligent tools for processing and understanding of the various kinds of images and videos due to the phenomenal progress made in the scale and manufacturability of imaging sensors over the past two decades.

Despite technical advances, demand continues for better, cheaper, and more capable imaging systems. For example, the defense and security industry is continuously seeking higher resolution images that facilitate detection and discrimination of objects at longer ranges and over larger areas. The bio-medical field is continuously seeking the ability to see smaller and finer details in tissues, often at the cellular or even at molecular and atomic level. Whether the goal is to gather intelligence information or diagnose diseases, the need to advance the state of the art of imaging will be growing for the foreseeable future.

The economic impact of this field is substantial: imaging science enables and empowers industries like defense, aerospace, homeland security, healthcare, bio-medical, space exploration, digital records, communications, transportation, manufacturing, agricultural research, entertainment and arts. Further technological breakthroughs in imaging science will enable new industries, not even conceived today. Imaging, in all its variety of applications, accounts for several billion dollars in the U.S. economy alone.

What is being proposed? This is a five-year project. Each year, ten math majored undergraduate (sophomore or junior) students are selected to participate in an intensive year-long training in computational mathematics with an integrated research component in computer vision and imaging science. The program starts in January and continues through December. Typically, during the first semester (January through April), a student takes five courses (see Section 2.1 for the descriptions of courses) and one seminar (one-hour) course specially designed to introduce computer vision and imaging science content. The second semester, the summer (May through mid-August), will be a full-time immersion in research. During the first three weeks of the summer, the topics from the seminar will be dealt with in depth, and will provide sufficient background to begin to undertake a research project in computer vision and imaging science that requires computational mathematics (mostly in calculus of variation, numerical linear algebra, and numerical solutions of PDEs). Each student will need to choose a research topic/direction by the end of the fifth week of the summer. After choosing a research topic, each student will be assigned to two faculty advisors: one main advisor from Math, another from Computer Science. The advisors will guide the research of each student in all the stages. There are three milestones (stages): 1. research proposal (presented to the advisory faculty by the eighth summer week, to describe the background and outline possible solution); 2. defense (presented to the advisory faculty around the middle of the third semester which runs mid-August through mid-December, and to present new results); 3.

publication (write a first draft of a research report by the end of the third semester, advisors will recommend an appropriate publication venue depending on the significance of the research results; each student will then polish this paper for submission and will write an undergraduate honors thesis based on the research in this submission, writing completed during the follow-up semester). Both the thesis and the polishing of the paper occur during a fourth semester (without NSF support but most will be supported through other funded projects) which is not part of the twelve months, but which ensures that the student does not cease involvement in research and publication activities after the twelve months (with NSF support). Some students will graduate at the end of this fourth semester. Others will graduate a year later. Those whose graduation is imminent will be applying to grad schools during the end of their follow-up semester. Their graduate applications will be strengthened due to their participation in CSUMS and their evidence of competence in computational issues. Those with another year to go can expect their grad applications to include an accepted publication in a refereed venue. To enable students to have this advantage, we will encourage sophomores to participate in CSUMS.

While our proposed research topics are presented as though they are completely individualized, in practice the students work in teams addressing different components of larger systems.

As institutional commitment to this project, the University of Central Florida is matching the NSF amount by more than 30%. This will go toward covering the salary of the co-PIs, the costs of two graduate students who will assist in tutoring the participants, and laptops for the participants.

2 Nature of Student Activities

2.1 Course Descriptions

Our existing curriculum in computational mathematics provides an ample opportunity for students to acquire knowledge in applied mathematics and computer sciences. However, without the exciting and understandable motivating examples, it is hard for students to see the connection between the theory and real world application problems. Our CSUMS will develop new courses as well as update existing courses. In the required course work, students will acquire a solid foundation in the theory and practice of programming, mathematical modeling and simulation, and numerical algorithms. They will also master elements of computer vision and imaging science. These courses will prepare students to understand recent research papers on their chosen research topics.

Numerical Methods for Computational Sciences This is a new course to replace the existing course *Numerical Calculus.* It serves as the introduction to numerical analysis in the CSUMS program. Covering the traditional topics and error analysis, this course puts emphasis on the modern research tools and methods in numerical computation. In particular, iterative method for solving linear systems, eigenvalue problem, singular-value decomposition, nonlinear optimization methods, Runge-Kutta methods, finite-difference scheme, an introduction to finite element methods for solving differential equations, and interpolation and approximation of functions will be discussed. This course will use Matlab and C. In addition to the topics mentioned above, some key ideas of parallel computation in a shared memory environment and in a distributed memory paradigm will be introduced through the introduction of adaptive quadrature and matrix multiplication.

Mathematical Modeling, I This is the updated and restructured version of the existing course *Mathematical Modeling.* We will add more computational components and emphasize issues and practical problems in computational mathematics. Students will be trained in (1) the procedures and strategies on how to transform a real world problem into a mathematical one, (2) how to analyze the problem numerically and analytically, and (3) how to find a solution numerically and analytically. The course will also be a platform for students to see various applications of mathematics in image analysis, bio-imaging, bioinformatics, finance, and telecommunication. The course will use discrete models and be based on difference equations.

Mathematical Modeling, II This new course on mathematical modeling treats more advanced problems at a higher level. From the discrete models in the first course, this course will treat (1) continuous models using differential equations, and (2) statistical and probabilistic models. The main applications will include video analysis, optimization and optimal control, mathematical biology, and fluid mechanics. The course will be project oriented. It will prepare students for different research fields in applied and computational mathematics.

Weekly One-Hour Seminar This will include presentations by the PIs on topics from an undergraduate computer vision and image processing class, but will only cover lectures, no homeworks. The students will repeat the material in more depth during the first three summer weeks. The topics include, image formation models, denoising, signal analysis, edge detection, object matching and recognition, stereopsis, motion tracking, machine learning techniques. In addition, they will be exposed to algorithms from statistical computing, bio-imaging, and numerical optimization. All these topics will be presented with numerous applications from real world problems.

Advanced Computer Vision In this new topics course, recent computer vision papers are discussed. For each class meeting, one paper is selected and assigned to a particular student. All students read the paper carefully before the class and prepare a report consisting of a short summary of paper, good points, weak points, questions, new ideas etc. The assigned student presents the paper for first 30 minutes of the class, the remaining time is spent in a group discussion, where all students participate. We have found that this is very efficient way to understand research papers and get good ideas for new work.

2.2 Sample Research Projects for CSUMS Participants

This section briefly outlines **some example** research projects for the CSUMS participants. During week 4-5 in summer, the PIs will present the participants with a greater number of possible research topics than there are participants, so that each student will be able, within these limits, to **choose** a project topic rather than have one **assigned**. This approach has proven successful with our past experience working with undergraduate students.

2.2.1 Sample Project: Spatiotemporal Regularity Flow (SPREF)

We have proposed in [8] and [9] a new spatiotemporal feature that represents the directions in which a video is regular, i.e. the pixel appearances change the least. The directions of regularity of a video are determined by its spatiotemporal properties. These properties depend on the spatial structure of the scene and the motion contents of the video. Explicit modeling of the directions of regular variations can be useful in many applications such as video compression, image and video in painting, object removal, tracking and segmentation.

SPREF ($\mathcal{F}$) is a $3D$ vector field that shows the directions, along which an intensity I in a spatiotemporal region Ω is regular, i.e., the pixel intensities in the region change the least. The condition that the intensity should vary regularly in the flow direction can also be perceived as a requirement to follow the directions, in which the sum of directional gradients is minimum. This allows us to write the general flow energy function, for $\mathcal{F}$ as

$$E(\mathcal{F}) = \int_{\Omega} \left(\frac{\partial(I \star H)(x,y,t)}{\partial \mathcal{F}(x,y,t)}\right)^2 dxdydt, \quad (2.1)$$

where H is a regularizing filter, such as a Gaussian. In SPREF, we choose one of the main coordinate axes (x, y or t) to be the axis of flow propagation for simplicity. The magnitude of the flow component along the propagation axis is taken as 1. The magnitudes of the remaining components are determined by minimizing the flow energy function (2.1) according to the flow models, which is only relevant to the propagation axis. Thus, the components of the SPREF along each propagation direction are translational.

In our framework, a *cross-sectional parallel* flow field consists of the following three components: *xy-parallel* ($\mathcal{F}_t$), *xt-parallel* ($\mathcal{F}_y$), and *yt-parallel* ($\mathcal{F}_x$). In an *xy-parallel* flow, the vectors on the xy plane of the flow field for a particular t are cross-sectional parallel. The planar parallelisms are similarly defined for the xt and *yt-parallelism*, where the flow propagation axes are x and y respectively.

All the three components of SPREFs can be formulated by discretizing the continuous flow energy function (2.1), and tailoring it according to how $\mathcal{F}$ is defined. If the flow is *xy-parallel*, then $\mathcal{F}$ is defined as $\mathcal{F}_t = (c_1'(t), c_2'(t), 1)$, which results in

$$E(\mathcal{F}_t) = \int_{\Omega} \left(\left(I \star \frac{\partial H}{\partial x}\right) c_1'(t) + \left(I \star \frac{\partial H}{\partial y}\right) c_2'(t) + I \star \frac{\partial H}{\partial t}\right)^2 dxdydt. \quad (2.2)$$

This is a good research project, with rigorous mathematical foundations, as well as intuitive real world applications. The students will be first introduced to the related work [8, 9] and relevant concepts like splines, wavelets, nonlinear minimization, etc. Next, the participants will be shown the demo and provided the source code. We propose to develop a new object tracking approach using SPREF. Since SPREF curve gives the direction of regularity, which essentially is the track of a moving object in video, object tracking should be possible in SPREF framework.

2.2.2 Sample Project: Sparse Recovery and Its Applications to Image Analysis

There are many situations that require the estimation/recovery of missing pixels in an image or video frame using the information provided by the nearby pixels. For example ([13]), in image and video compression applications over unreliable channels the decoder has to contend with data corrupted by channel errors. These errors lead to missing pixels or distortion to the uncompressed image and video which must be estimated/recovered under a fidelity criterion by appropriate recovery and concealment algorithms. How many remaining pixels are needed to allow a complete recovery? In image compression, what is missing is part of the encoded data (e.g., wavelet coefficients), not the pixels, then how many data values must remain to ensure a possible recovery? In this research topic, we investigate the most recently developed techniques of sparse recovery and its application to image recovery. Mathematically, a finite digital signal or image is equivalent to a vector in a finite dimensional space. It is a common task to recover a vector $\mathbf{x} \in \mathbb{R}^d$ from a number of its linear measurements in the form of linear filters: $y_1 = \mathbf{a}_1^T \cdot \mathbf{x},\ y_2 = \mathbf{a}_2^T \cdot \mathbf{x}, \cdots, y_k = \mathbf{a}_k^T \cdot \mathbf{x}$ where $\cdot$ denotes the inner product operation. When the number of observation is no smaller than the dimension of the vector to be recovered, it is reasonable to recover $\mathbf{x}$ from the observations $\mathbf{y} = (y_1, y_2, ..., y_k)^T$. When the dimensional is bigger than the number of observations, in general, it is not possible to uniquely determine $\mathbf{x}$ from its observations $\mathbf{y}$. During the past few years, *sparse* recovery has been shown possible by using the l^1 linear and convex programming techniques ([14]-[22], [24]-[26]).

In order to recover sparse signals, it has been shown ([14],[15],[23],[24]) that the linear filters $A = [\mathbf{a}_1,\ \mathbf{a}_2,\ \cdots,\ \mathbf{a}_k]$ need to satisfy the uniform uncertainty principle (UUP). The proposed research project will start with experimentation with the known examples of such filters. In the design of numerical experiments, noise in the observations will be added as well in order to examine the stability of the recovery methods. The insight gained from the results of the numerical experiments will be used in the next step: finding theoretical basis. In this step, criteria will be developed as guide in order to search for new sets of filters that satisfy UUP. Another practical problem is to find simple ways (i.e., sufficient conditions) to check if a given set of filters obeys UUP. Finally, to demonstrate the use of the method, extensive numerical experiments using examples from image recovery will be done. The main tools of research will be based on analysis and optimization.

2.2.3 Sample Project: Image Denoising via Partial Differential Equations

Variational method and partial differential equations are widely used in image analysis. This project will lead the students to a forefront of the research in the current research area of applications of numerical partial differential equations.

The search for efficient image denoising techniques is still on. In spite of the sophistication of the recently proposed methods, the algorithms have not yet attained a desirable level of applicability. A digital image is generally encoded as a matrix of gray level or color values. In the case of a video, this matrix has three dimensions, the third one corresponding to time. Each pair $(i; u(i))$ where $u(i)$ is the value at i is called pixel. In the case of gray level images, i is a point on a 2D grid and $u(i)$ is a real value. In the case of classical color images, $u(i)$ is a triplet of values for the red, green and blue components. We shall focus on rectangular 2D gray-level images. The two main limitations in image accuracy are categorized as blur and noise. Blur is intrinsic to image acquisition systems, as digital images have a finite number of samples and must respect the Shannon-Nyquist sampling conditions [31]. The second main image perturbation is noise. One can write

$$v(i) = u(i) + n(i);$$

where $v(i)$ is the observed value, $u(i)$ would be the "true" value at pixel i, and $n(i)$ is the noise perturbation. In noise models, the normalized values of $n(i)$ and $n(j)$ are assumed to be independent random variables, this model is called "white noise".

The proposed research project starts with a comparison of several well known existing denoising methods. Since there is a rich literature related to these methods and proposed improvements, the best currently available version will be sought. The following methods will be looked at:
(1) the Gaussian smoothing model (Gabor [29]), where the smoothness of u is measured by the Dirichlet integral $\int |Du|^2$,
(2) the anisotropic filtering model (Perona-Malik [30], Alvarez et al. [27]), and
(3) the Rudin-Osher-Fatemi [28] total variation model.
Implementation of the various methods will be part of the task. Indeed, the research project will try to find the most appropriate implementation for each method, analyze the numerical algorithm in terms of convergence, and make a recommendation based on the analysis and the associated numerical experiments. This research project requires knowledge of calculus of variation and numerical solution of PDEs.

2.2.4 Sample Project: Computation of Motion in Image Sequences

Automated computation of motion in image sequences is a challenging task in image processing. It has applications in animal, human, and vehicle surveillance, weather prediction from Doppler Radar, and MRI or PET data of a human beating heart, among others. One way to estimate the motion in a sequence is to compute the optical flow field (or image velocity vector field) that approximates the image motion.

Assume that $I(x, y, t)$ represents the brightness of the image at the location (x, y) in frame t (i.e., at time t). Suppose that $x = x(t)$ and $y = y(t)$ are the parametric equations that describe the displacement of a point of interest at time t. Then, according to the brightness conservation principle, the so-called *gradient constraint equation* holds:

$$I_x u + I_y v + I_t = 0, \qquad \text{with } u = \frac{dx}{dt} \text{ and } v = \frac{dy}{dt},$$

where I_x, I_y, and I_t denote the partial derivatives of I. As (u, v) depends on (x, y, t), it is referred to as the optical flow field. Since the gradient constraint equation cannot determine two unknowns u and v at each pixel, we have to introduce additional constraint. In their seminal paper, Horn and Schunck ([32]) considered the requirement that the square of the gradients of u and v be small. More precisely, they proposed to minimize (on image domain Ω):

$$\iint_\Omega (I_x u + I_y v + I_t)^2 + \alpha(|\nabla u|^2 + |\nabla v|^2) dxdy \to \min$$

which has the following Euler-Lagrange equations:

$$\Delta u = (I_x^2 u + I_x I_y v + I_t)/\alpha, \text{ and } \Delta v = (I_x I_y u + I_y^2 v + I_y I_t)/\alpha,$$

where $\alpha > 0$ is a prescribed constant and Δ denotes the Laplace operator (in x and y). These equations can be solved using finite difference method. Due to the fact that the integral above is taken over the whole image domain Ω, this method is global. Lucas and Kanade ([33]) introduced a local method using the assumption that optical flow in a small window on the image should be about the same. Both Horn/Schunck and Lucas/Kanade methods have been extended (see [34, 35] for more references). For this project, we propose the following questions:
(1) Is there a good way to choose α? Carefully designed numerical experiments can shed light on the pattern for choosing this constant.
(2) The L_2 norm is used in the formulation above. What happens when L_1 norm is used in one or both terms?
(3) Both Horn/Schunck and Lucas/Kanade methods suffer from the drawback at the boundary. Will inserting some special weight function in the integral improve the estimation near boundaries? In particular, one should try using bileteral filters.
(4) Provide convergence analysis for the various optical flow estimation methods, including the Horn/Schunck method.

Students participating in this project will have the opportunities to go through each stage of mathematical modeling, problem formulation, numerical experiments, and eventually solve some real research problems of real life applications.

2.3 Project Schedule

Orientation

About two weeks before the New Year, students selected for the upcoming twelve month CSUMS program will be brought together for a two-day workshop in which they will be able to meet all the faculty advisors and graduate student assistants in the CSUMS project. Semester course schedules will be distributed to all students. Basic rules will be laid out. Students will have lots of opportunities to get familiar with the faculty and ask them questions. Textbooks, software, and teaching materials will also be distributed.

Spring Semester

All participants will take: (1) Numerical Methods for Computational Sciences and (2) Mathematical Modeling I in addition to their three required courses in their program of study during the Spring semester. All participants will also attend the one-hour weekly seminar.

Week 1 – Week 3, Summer Semester

During these three weeks, the PIs and senior personnel will provide intensive lectures and tutorials on the details of computer vision.

Week 4 – Week 5, Summer Semester

During this period, at least fifteen possible research projects will be discussed. Each participant will be asked to select a project. Sufficient background material will be provided to students to ensure a productive and smooth start on their projects.

Week 6 – Week 14, Summer Semester

Throughout these nine weeks, the participants will meet their research advisors regularly each week for guidance on their chosen research topic. They will prepare a presentation on their progress during the past week. The presentation will be about fifteen minutes and will sketch out progress made, delays encountered, dead-ends run into, help needed, and plans for the next week. At the end of the presentation, each participant should expect to get feedback comments and assistance from the PIs and any other research advisors, the graduate students assistants, and most importantly from their peers. This management structure will facilitate knowledge-sharing, group bonding, and solutions to most practical problems related the research. Also, the peer support factor and the public reporting keep the participants motivated to ensure that they have something to report each week.

By the end of Week 8, they should be prepared to write an outline of their proposed research project. Some will also possibly have conducted initial analytical analysis and numerical experiments.

Week 9 – Week 14

During these weeks the participants will be working hard to make progress on their projects.

Fall Semester

By this time, participants will have some preliminary research results. The weekly seminar will be used to reinforce their knowledge and provide a chance to learn more through reading current research papers in order to improve their research results. In addition to their normal required courses (three) they will take (1) Advanced Computer Vision and (2) Mathematical Modeling II. During this semester, the student will also present a defense of an initial set of results and will proceed to write up a draft of a research paper. The end of this semester will mark the official end of the CSUMS, but the student will continue in the following ("follow-up") semester to polish the paper for submission and to write a honors thesis (without NSF support).

2.4 Distinguished Speaker Series

UCF conducts a Distinguished Speaker Series in both Mathematics and Computer Vision, as part of its commitment to excellence. As part of this series, eight to ten world-class researchers (typically members of the National Academy of Sciences or the American Academy of Arts & Sciences, Fellows of IEEE and/or ACM and/or SPIE.) speak at UCF each year, and spend two days on campus. At least two of these are scheduled during the summer semester. All CSUMS participants will be invited to meet with the speakers in an informal discussion session where the CSUMS participants will be free to ask questions related to their research. Potential future speakers include the Fields Medalist Dr. David Mumford of Brown University whose recent work on Machine Vision and the Neurosciences will have a long lasting impact, Dr. R.R. Coifman of Yale University whose contribution to the diffusion-driven multiscale analysis on manifolds is making revolutionary changes in image representation and analysis, and Fields Medalist Dr. Stephen Smale of Toyota

Institute whose latest work on Mathematics of Learning, Algebraic Geometry and Computer Vision is very important.

Activity	Frequency	Dates
Orientation Kick-Off	two days	Around December 16
Classes		
Numerical Methods	Every M/W/F	Jan 3 – April 30
Math Modeling I	Every M/W/F	Jan 3 – April 30
3 other major's courses (Spring)	3 days/week	Jan 3 – April 30
Advanced Computer Vision	Every M/W/F	August 20 – Dec 14
Math Modeling II	Every M/W/F	August 20 – Dec 14
3 other major's courses (Fall)	3 days/week	Jan 3 – April 30
Seminar classes		
Intro Computer Vision	1.5 hours/week	Jan 3 – April 30
Project Progress Reports	1.5 hours/week	August 20 – Dec 14
Research Project		
Intro to Vision and Research	40 hours/week	May 2 – May 22 (weeks 1–3)
Consider Topics and Select one	40 hours/week	May 23 – June 6 (weeks 4–5)
Prepare research project proposal	40 hours/week	June 7 – June 28 (weeks 6–8)
Conduct research	40 hours/week	June 29 – Aug 15 (weeks 9–14)
Defend early Report/Paper	1	October/November
Write/improve paper	–	Till December 14
CSUMS Research Group Meetings	Weekly	Summer
Follow-Up Semester		
Write/improve paper for submission	–	January – April
Defend Thesis (Honors or other)	1	April
University-wide Poster Day	1	April 8
Attend Graduate Group Meetings	Weekly	Summer and Fall
Distinguished Speaker Series	2	Summer
Attend Professional Conference	One/year	Variable
Apply Grad Schools	as needed	Nov 1 – Feb 28
Career Mentoring	as needed	Nov 1 – April 28
Social Events		
BBQ Cookout	1	Mid-June
Buffet lunch	2	Late-June & Late-July
Banquet	1	December 14
Party with Distinguished Speaker	2	Summer
Party for graduating Ph.D. student	at least 2	Summer/Fall
Field Trips		
Company, e.g., Lockheed-Martin	2	Summer

Figure 1. CSUMS Activities Through the Year.

2.5 Professional Development

Attendance at professional meetings gives undergrads exposure to well-known researchers in the field, provides an opportunity to see polished and less-polished research presentations, and provides an opportunity to assimilate the latest research results. All of the CSUMS participants will attend at least one professional meeting to present their research results. In addition, important research findings will be submitted for publication. This is a great experience which will build self confidence in the students and motivate them to work hard.

2.6 Social Events

Our motto is: *if you work hard, then you must play even harder.* To ensure that this message is not lost in the midst of all the scholarly activity, we will schedule the following six strictly social events: 1) a BBQ-cookout for all the CSUMS participants; 2) and 3) two buffet lunches with the PIs; 4) two dinner parties at the home of one of the PIs where Distinguished Speakers of international fame will attend, 5) at least two dinner parties for any graduating Ph.D. students from Mathematics and the Computer Vision Lab, and 6) a dockers/dress-shirt "graduation" banquet at a restaurant at Disney that is comparable to the banquets at the major conferences/workshops (this will be held to mark the end of the twelve month period and is intended to give the participants the full experience of the professional research life). All these social events provide the PIs the venues to continue mentoring in non-scholarly aspects of the profession.

2.7 Field Trips

To give our CSUMS participants exposure to hi-tech industrial opportunities, we will arrange field trips to 1) a behind-the-scenes tour of the NASA Kennedy Space Center research groups, 2) Lockheed Martin's Fire and Missiles Division; and 3) Harris Corporation's Satellite Communication Labs. These serve as samples of industries that employ graduates of computational science M.S. and Ph.D. programs. We already have working relationships with these companies since they have been supporting our research over the years.

3 Connection to Regular Academic Studies

CSUMS will fit seamlessly with the required courses in students' program of study in computational mathematics. Indeed, mathematics and computer science departments have been working together for the existing computational mathematics track in our undergraduate program and all restrictive selective courses (18 hours) are offered by computer science. The proposed additions and updates of courses will help the department of mathematics to streamline our current computational track in our undergraduate program by emphasizing on both the mathematical foundation and interdisciplinary applications of computational sciences. This will result in a broader impact on a wide range of students in our undergraduate program.

1. We choose to start the CSUMS program in the Spring semester of the sophomore year so that the students will have enough time to take the pre-requisite classes during the four semesters before they enroll in the CSUMS program and will also have time of at least a year to publish their CSUMS research results before they apply for jobs or graduate study.
2. We feel the following assumption is realistic: During the first five semesters, a good candidate for the CSUMS would have finished (a) Calculus sequence (Calc. I, II, and III), (b) Physics I, (c) Statistics I, (d) Matrix/Linear Algebra, and (e) C programming language in addition to the other general education required courses. Potential participants will be advised to take all the courses in (a)-(e) during the prior semesters.
3. The newly developed courses will teach students how to transfer a real life problem into a mathematical problem and how to use computation and mathematics to verify, and how to experiment with the mathematical models.
4. The research activities throughout the whole year are designed to help students (a) relate their knowledge and skills in mathematics and computation with research topics in the first semester, and (b) improve their preliminary research results and reinforce their knowledge in mathematical analysis, statistics, and programming skills in the second semester.
5. The proposed CSUMS program will not only teach all participants the fundamentals of computation and mathematical skills, but also make them better understand the other courses required by their regular program of study. By the end of the CSUMS program, all students will be have a deeper appreciation of some famous results in mathematical analysis, linear algebra, and statistics, like the Intermediate Value Theorem for continuous functions through the bisection method, the Mean Value Theorem and the Taylor Theorem through Newton's method and the secant method, the Riemann integrals through quadratures, the eigen-values and singular values through PCA, linear independence through sparse recovery, conditional probability through the EM method and HMM, etc.

4 Research Environment and Mentoring Activities

4.1 Faculty Expertise: PIs

Almost two decades of track record of the PI in mentoring about two hundred undergraduates in Computer Vision area at the University of Central Florida forms the foundation for this interdisciplinary team effort of implementing a CSUMS training program at UCF. We are confident that the experience and dedication of the team members from Mathematics and Computer Science will ensure the success of the proposed CSUMS program at UCF.

Dr. Mubarak Shah (P.I.), Agere Chair professor of Computer Science and Mathematics, and the founding director of the Computer Vision Laboratory at the University of Central Florida, is world known researcher in computer vision. In 2006, Dr. Shah was awarded Pegasus Professor Award. This is the highest award given to any faculty, and it recognizes a faculty member who has made a significant impact on the university, has made an extraordinary contribution to the university community, and has demonstrated excellence in teaching, research and service. Dr. Shah is a **Fellow** of the **IEEE** and **IAPR** (International Association of Pattern Recognition). He was an IEEE Distinguished Visitor speaker for 1997-2000, and is often invited to present seminars, tutorials and invited talks all over the world. He received the Harris Corporation Engineering Achievement Award in 1999, the TOKTEN awards from UNDP in 1995, 1997, and 2000; Teaching Incentive Program award in 1995 and 2003, Research Incentive Award in 2003, IEEE Outstanding Engineering Educator Award in 1997. He is an editor of the international book series on "Video Computing"; editor in chief of Machine Vision and Applications journal, and an associate editor of the journals, ACM Computing Surveys, and Pattern Recognition. He was an associate editor of the IEEE Transactions on PAMI. He is author of several books and over 160 papers.

Professor Shah has supervised many Ph.D. and M.S. students and is currently supervising a large number of Ph.D. students. He has conducted six short courses in four different countries. His pedagogical contributions are covered in three text books by popular authors: *Robot Vision* (Haralick and Shapiro), *Introductory Techniques for 3D Computer Vision* (Veri and Trucco), *Computer Vision* (Shapiro and Stockman), and taught in introductory classes in the US and all over the world.

Dr. Shah has worked with a large number of undergraduates throughout his career. These students have co-authored more than 60 research papers (in reputed journals, such as, PAMI, PR, CVGIP, and conferences, such as, ICCV, CVPR, ICPR). Approximately half of these undergraduates have gone to graduate schools, nine students have written Honors in the Major Theses, six undergraduates are now faculty members at Universities, and five have started their own companies. Dr. Shah has published two papers in the education related journal, IEEE Transactions on Education, on education and training. He co-organized the IEEE Course and Curriculum development workshop in 2001. Dr. Shah introduced a new undergraduate honors course "Computer Vision Guided Tour of Mathematics", which he co-taught with Dr. Li. The main objective of this course is to re-invigorate interest in mathematics among students to deal with the decline in enrollment in math related courses.

Dr. Xin Li (co-P.I.) is a professor of mathematics specialized in the research areas of approximation theory, stochastic process, and scientific computing. He has published over fifty research papers in high quality international journals including Annals of Statistics, Constructive Approximation, IEEE Transactions on Pattern Recognition and Machine Intelligence, Journal of London Mathematical Society, Mathematics of Computation, and is currently writing a monograph on approximation on scattering data.

In the past few years, Dr. Li has established a close collaboration with Dr. Shah and his research group in computer vision at UCF via applying new mathematical methods in solving problems in target recognition, object detection and tracking in video sequences. Some of the joint research results have been published in conference proceedings and a recent journal publication in IEEE PAMI, the top journal in computer sciences. Through the years, Dr. Li has fundings from various external funding agencies including National Science Foundation, Florida Department of Transportation, and Lockheed Martin Corporation.

Dr. Li, together with Dr. Shah, has developed and taught the Honors seminar course "Computer Vision Guided Tour of Mathematics" to present advanced concepts of mathematics to undergraduate students from the Honors college using meaningful real world application from computer vision. It helps students appreciate more advanced mathematics and encourages more students to study sciences and mathematics.

In order to prepare students in mathematics for the advanced, graduate level numerical analysis courses, in their skills of both programming and mathematical analysis, Dr. Li introduced a course "Scientific Computing" in 2001 in which both programming languages and fundamentals of numerical analysis are thoroughly covered. Dr. Li received the Teaching Incentive Program (TIP) Award in 1994 and 2003 for his undergraduate and graduate teaching activities at UCF.

Dr. Niels Da Vitoria Lobo (co-P.I.) is an Associate Professor of Computer Science. He received the B.Sc. (Honors) from Dalhousie University, Canada, and the M.Sc. and Ph.D. from U. of Toronto. He joined UCF in 1993, and since then has supervised over 15 Ph.D., M.S., and B.S. theses to completion.

Dr. Lobo's research interests are in computer vision, and modeling for real-time computer graphics. He co-authored a book ("Visual Event Detection", Kluwer, 2001), which offers a framework for handcrafting event recognizers. In addition, he has worked in the areas of object recognition and tracking. His recent areas of interest are human posture analysis and activity recognition, including using the GPU for performing these tasks in real-time. He has published over 60 refereed papers in journals and conferences, and has received funding from many agencies. He was Program co-Chair for the 2002 IEEE Workshop on Applications of Computer Vision. He has been very active in the management of UCF's Computer Vision REU site for the past several years, and has published many refereed papers with undergraduates.

In 1996, he received the State of Florida Teaching Incentive Program (TIP) Award. He has four patents, with his students as co-inventors. He has been the faculty advisor for the highly visible ACM student chapter for the past ten years. Currently, he has four Ph.D. students, and four B.S. students pursuing research under his supervision.

Dr. Piotr Mikusinski (co-P.I.) is a professor and chair of mathematics. He received his Ph.D. in mathematics from the Institute of Mathematics of the Polish Academy of Science. Dr. Mikusinski joined UCF in 1985 and is currently serving as the chair of the Department of Mathematics. He's the author of more than 60 research papers, mainly on generalized functions and doubly stochastic measures. He has extensive experience in both undergraduate and graduate education. One of his undergraduate students won the prestigious Best Paper Award of MAA based on his research with Dr. Mikusinski (Anthony De Lia, A Vector-Valued Daniell-Type Integral, 1993). His contribution in pedagogical aspect of education is reflected in his textbooks "Hilbert Spaces", "An Introduction to Analysis: From Number to Intrgral" and "An Introduction to Multivariable Analysis: From Vector to Manifold," which have been widely used by universities around the world. Although trained as a pure mathematician, Dr. Mikusinski deeply appreciates the computational skills in the training of future mathematicians. Through his advocation and effort, now a year-long sequence of Computational Mathematics is part of the required core courses for all students in the mathematics graduate program. As the chair, he is in a good position to coordinate the proposed improvements in the undergraduate curriculum and research.

Dr. Constance Schober (co-P.I.) is an Associate Professor of Mathematics. She received her B.A. and M.Sc. from New York University and her Ph.D. from the University of Arizona. Prior to joining UCF in 2002, she was an Assistant Professor at Old Dominion University.

Dr. Schober's research interests are chaotic dynamical systems, large amplitude rogue waves, and geometric integrators for nonlinear wave equations. Dr. Schober has published forty four research papers in journals such as the Journal of Computational Physics, Physics Letters A, Physical Review Letters, Physics of Fluids etc. and is currently contributing to a monograph on Extreme Waves. She has been invited to give over 70 lectures at universities and conferences all over the world. Her research has been continuously supported by the NSF since 1997.

Dr. Schober has been very active in directing both undergraduate and graduate research. She has supervised 5 Ph.D. and M.S. students and is currently directing the research of two undergraduates. She has developed a new course Numerical Partial Differential Equations at UCF. Dr. Schober is a co-founder and co-organizer of the NSF funded SEAMS workshop (since 2004) for undergaduate and graduate students. She is a co-PI on the NSF funded EXCEL program at UCF for improving the retention rates of students in mathematics and the sciences.

4.2 Senior Personnel

In addition to the PIs, the following senior personnel will serve as research advisors, or instructors of the required courses, or evaluator of the CSUMS project.

Dr. Conrad G. Katzenmeyer is currently the Chairman of the Department of Educational Research, Technology and Leadership in the College of Education at UCF. Prior to joining UCF, he served as the Senior Program Director for Evaluation of the Division of Research, Evaluation, and Communication at the National Science Foundation from 1993 to 2005. Dr. Katzenmeyer is the recipient of the 2004 Alva and Gunnar Myrdal Government Award given by the American Evaluation Association to an individual who has made significant contributions to evaluation in a government setting. As a researcher, a practitioner, and an administrator in evaluation, Dr. Katzenmeyer is an educational research expert in planning, implementing, and conducting evaluations for various educational agencies from local schools, to school districts, and to NSF funded national projects.

Dr. Katzenmeyer will serve as the lead evaluator and be responsible for the oversight and coordination of the evaluation for the proposed CSUMS program at UCF.

Dr. Robert Muise is a senior staff engineer in the Research & Technology Department at Lockheed Martin - Missiles & Fire Control, Orlando. He received his Ph. D. in Mathematics, while working full time at Lockheed Martin, from the University of Central Florida in 2003. He has more than sixteen years of experience working as a mathematician in industry. He has led an engineering team in developing algorithms for automatic target detection/recognition in images for DoD contracts (DARPA) and internal LM-MFC research and Development (IRAD). He conducts Research and Development in automatic target recognition/detection, image processing, global change detection, object tracking, and information fusion. He has technical expertise in computational linear algebra, multi-scale algorithms and transforms, statistics and classification algorithms, image registration, multi-dimensional image processing algorithms. He has been an adjunct professor at UCF since 2003 teaching various undergraduate courses.

Dr. Zuhair Nashed received his S.B. and S.M. degrees in electrical engineering from MIT and Ph.D. in mathematics from the University of Michigan. He served as an Assistant, Associate and full Professor at the Georgia Institute of Technology, and as a Visiting Research Professor at the Mathematics Research Center at the University of Wisconsin. He also held visiting appointments at several institutions in North America and abroad, and gave lectures in numerous distinguished lecture series. Most recently Dr. Nashed served as Professor of Mathematics and Electrical Engineering at the University of Delaware before he joined the faculty of the University of Central Florida in 2002. Dr. Nashed's research interests are in integral and operator equations, inverse and ill-posed problems, numerical analysis, nonlinear functional analysis, optimization and approximation, and signal analysis. He has published over 130 papers, 5 edited books, and several expository articles. He is the editor of Numerical Functional Analysis and Optimization and the Journal of Integral Equations and Applications, and serves on the editorial boards of 12 journals.

Dr. Yuanwei Qi is an assistant professor of mathematics. He received his M.S degree from the Chinese Academy of Science in Computational Mathematics and his Ph. D. in Mathematics from University of Oxford, UK, in 1990. He is an established researcher in scientific computing to effectively capture pattern generation, wave propagation and global dynamics in reaction-diffusion systems and in nonlinear partial differential equations and their applications in biological pattern formation, chemical reaction and population dynamics. In his teaching career of more than 15 years in UK, US and Hong Kong, Dr. Qi has done many projects related to undergraduate research.

Dr. Jiongmin Yong is a professor of mathematics specialized in the research areas of optimal control theory for deterministic and stochastic systems, differential games, mathematical finance, and stochastic differential equations. He is one of the founders of forward-backward stochastic differential equations, and a pioneer in solving various mathematical finance problems by forward-backward stochastic differential equations. Dr. Yong's current research is funded by NSF. He has published over 100 research papers and has co-authored several monographs, including: **Optimal Control Theory for Infinite Dimensional Systems** (Birkhäuser, 1995) and **Stochastic Control: Hamiltonian Systems and HJB Equations** (Springer, 1999). He was an associate editor of *SIAM Journal on Control and Optimization* (1998–2004), *ESIAM: Control, Optimization, Calculus of Variations* (2003–2005). Currently, he is an associate editor of the *Journal of Applied Mathematics and Stochastic Analysis* (1994–), *Annals of Economics and Finance*, and *Acta Mathematicae Sinica*.

Since the summer of 2006, Dr. Yong has been involved in research related to image processing/computer vision. He, jointly with Drs. M. Shah and X. Li, introduced a method of optimal control to approach some denoising problems in the area of computer vision. Such a method has a great potential in approaching some other related problems in the area of computer vision.

4.2.1 Student-Faculty Interaction

The appropriate level of student-faculty interaction and supervision of the participants will be achieved by the following means:

Weekly Individual Meetings One of the research advisors for each participant will hold a weekly individual meeting with the participant to discuss the research project.

Office Hours Each PI will set aside at least one hour per week of office hours strictly for CSUMS students. The students will have a chance to ask questions and discuss projects during this time in addition to their regular weekly meetings.

GTA Office Hours Two graduate student tutors (one from Math and one from Computer Science) will also hold 10 hours weekly office hours for CSUMS participants. The participants will be able to discuss matters related to the courses, programming, implementation details.

Weekly UCF Computer Vision Research Group Meetings The PIs hold a weekly seminar-style meeting with their graduate research group, in which current research papers are discussed, upcoming presentations by group members are rehearsed and discussed, papers by group members are "pre-reviewed", participants give presentations on the status of their project, etc. This meeting is held in the evening and starts with an informal dinner for the whole group and takes roughly two hours. The CSUMS participants will attend these meetings as observers, and will be encouraged to make comments, participate in discussions, ask questions, etc.

CSUMS Group Meetings The whole CSUMS group, consisting of PIs and CSUMS students will meet weekly during the whole year. In Spring, this will be for the Seminar; in Summer, it will be for progress reports; and in Fall, it will be to ensure that all the students are on target to be able to defend their project results, and to write up a draft of a paper.

4.3 Research Environment

The University of Central Florida currently enrolls over 49,000 students and is among the fastest growing universities in the country (enrollment is expected to exceed 60,000 within the next decade). UCF is strategically situated in one of the nation's most dynamic metropolitan areas. In addition to being the nation's center for entertainment and entertainment technology, the Orlando area is one of the most advanced high-tech areas in the South-East, and hosts by stalwarts such as Lockheed-Martin, Siemens, the Naval Training Systems Center, NASA Kennedy Space Center, Harris Corporation, Boeing, Oracle, ATI-Research, Electronic Arts Systems, and all the industries in the Central Florida Research Park. Orlando is at the center of Florida's High Tech Corridor, home to thousands of new and emerging high-tech companies. Growth in Orlando is fueled by year-round excellent weather, beautiful natural scenery with beaches on two coasts, and an enviable quality of life obtained at a low cost.

The Department of Mathematics is the largest unit in the College of Sciences at UCF. It has a strong teaching and research tradition in classical analysis including approximation theory, special functions, partial differential equations, sampling theory, asymptotics, and wavelets and harmonic analysis. The department also has a group of world renowned faculty in applied mathematics in the areas of laser propagation in random media, nonlinear waves, dynamic systems, and fluid dynamics. The department is currently building a small cluster of SUN workstations and DELL PCs for a computing lab for faculty research which can be used for the CSUMS program when small scale parallel computing is required. The faculty research is funded by state and federal funding agencies and industries such as NSF, ARO, NAS, FDOT, FDOE, Boeing, Lockheed Martin, etc. The department is growing and is hiring at the rate of about two to three new faculty members per year in the past few years. The department is currently having 77 active graduate students taking course works and working on various research projects in computer tomography, imaging analysis, mathematical biology, statistics, nonlinear dynamics, wavelet analysis, approximation theory, etc.

UCF's School of Electrical Engineering and Computer Science (EECS) has just moved into a brand new 100,000 square-feet building, with state of the art laboratories and an attractive environment for faculty-student interaction. According to Google UCF Computer Vision Lab [1] web site is the second most visited web site in the world. The Computer Vision group currently consists of about twenty Ph.D. students, three post docs, a programmer, lab manager, and a couple of visitors. The research is funded by NSF, DARPA, ARDA, ARO, FDOT, Lockheed Martin, etc. Funded projects include: Human Detection, Ground Reconnaissance Video Analysis, Night Time Surveillance, Automatic Target Recognition, Visual Monitoring of Rail Roads, Cooperative Groups of UAVs in Sensing Applications, UAV Video Indexing.

The CSUMS students will be integrated with the graduate students in both mathematics and computer science, and this environment has been very successful in stimulating the undergraduates and leading to research publications by the undergraduates in the past. The PIs have published over sixty-eight refereed papers with undergraduates over the past 18 years.

The UCF Provost, Dr. Hickey, has made undergraduate research a top Priority and has sponsored the creation of an undergraduate research journal [6]. In addition to the CSUMS program that is the subject of this proposal, UCF currently has NSF REU sites in Computer Vision, Physics, Robotics, Materials, AeroSpace and Laser-Optics. UCF's undergraduate population now includes hundreds of National Merit Scholars.

5 Student Recruitment and Selection

We will primarily look for students from the pool of undergraduate math majors (including double majors in mathematics) who will be sophomores or juniors in the Fall semester of each year, who have a GPA of at least 3.25, and who have a strong capability in Mathematics. Each candidate will be asked to complete an application form. After an initial screening, the PIs will interview the potential participants individually and decide who should receive offers. It is planned that each year at least *five* of the ten participants will be women and/or minorities. Our past experience indicates that this is an achievable goal. We have already contacted the Minority Programs offices at UCF and will have their help in recruitment.

- We will widely broadcast the CSUMS project to students in all our contact with the undergraduate math courses, including the Honor's Seminar the PIs are teaching (Shah and Li), Numerical Calculus (Shah and Lobo), Advanced Calculus I (Mikusinski), Linear Algebra (Li and Mikusinski) and the Honor's Seminar on Weather Forecasting (Schober).
- During the semester, to increase the impact and awareness of the CSUMS project, selected groups of math majors not in the program will be invited to participate in various CSUMS activities, including seminars and social events.
- We will participate in the annual event of *Math Day* organized by the department of mathematics that showcases mathematics and its applications to high school and undergraduate students.
- One of the Co-P.I.s (Schober) is a co-PI on the NSF funded EXCEL program (for five years) for retaining students in mathematics and the sciences. This program deals with students at the beginning stage of their career, in Calculus and Differential Equations courses. We will recruit math majors from EXCEL into the CSUMS project.
- The P.I. and one of the Co-P.I.s (Shah and Lobo) have recently been awarded a grant from NSF's ITEST Program (Information Technology Experiences for Students and Teachers) to work with local Math teachers and students to integrate imaging science modules into the core Math courses in high school. As part of that project, the UCF team is working closely with Math teachers and specialists in the school district, and also with school Principals and guidance counsellors. Our connections and relationships with the district administrators, Math teachers and students will serve as a platform to recruit Mathematics majors to the CSUMS project.
- We will work closely with the McNair Program at UCF to recruit high talent minority students to Math Majors and to this program.

6 Project Management

Dr. Shah and Dr. Mikusinski will oversee management of this project, assisted in day-to-day management by the co-PIs, Dr. Li, Dr. Lobo, and Dr. Schober. Dr. Mikusinski will coordinate the course offerings, teaching assignments, and new courses implementation, making sure that appropriate resource and computer lab time are reserved for the CSUMS participants. The PIs will be involved in screening, selection, and supervising students. All PIs will supervise at least one research project. In addition to teaching some of the required courses for CSUMS participants, Senior personnel (Dr. Nashed, Dr. Yong, Dr. Qi, and Dr. Muise) will serve as additional research advisors, provide research topics, present talks in the seminar, and mentor students in general. Two graduate students supported by this grant (through UCF matching funds) will assist the PIs in management, coordinating the various activities, and will assist the participants with their studies and computing-related issues. In addition to support from people formally involved in CSUMS project, informal help from a large number of Ph.D. students and post docs from both mathematics and computer sciences will also be available.

Question	Information Needed	Source	Method
To what extent do the participants increase content knowledge in computation and mathematics?	Assessment test scores	Pre and post mathematics tests	Quantitative analysis
What are the perceptions of content, preparedness for curriculum, learning engagement behavior, confidence level?	Course syllabus	Baseline perceptions and knowledge survey	Quantitative analysis
How effective are program recruitment strategies and activities?	Recruitment plan	Student statistics: number of major supported number of fields served Demographic data	Quantitative analysis
To what extent does the participants' deepened knowledge in computation and mathematics prepare them for more advanced studies?	Participants transcripts	GRE scores, graduate school application status	Quantitative analysis
To what degree do participants believe that the project has impacted student learning?	Participant reports of high level course to be taken	Participants survey	Quantitative analysis
How effective are the classroom mechanisms?	Monthly meetings, classroom observations	Participants survey	Qualitative analysis

Figure 2. Planned Assessment Activities

7 Project Evaluation and Reporting

The evaluator, Dr. Katzenmeyer, and his research assistant will work with the PIs from the beginning and throughout the CSUMS project. They will be participating in designing the pre- and post- tests, monitoring the implementation and progress of the project, providing feedback to the PIs for continuous improvement, and collecting and maintaining the useful data about all the activities of the CSUMS project.

The proposed evaluation and assessment strategy will play a crucial role in validating and directing the project activities, outcomes and deliverables. The plan will evaluate and assess both product and process in order to ensure the project goals are met and will be assessed using a continuous improvement approach. For the purpose of this research proposal, an "objectives-oriented" evaluation is appropriate. The main purpose of an objectives-oriented evaluation approach is to determine whether or not the main objectives of the program have been achieved. Stufflebeam (2001) states : "The objectives-based approach is especially applicable in assessing tightly focused projects that have clear, supportive objectives" ([36, p.17]). An experimental research design is not suitable for this evaluation because the population of 10 participants is too small.

Participants' gains in computation and mathematics knowledge is a core objective of this project and will be measured before the CSUMS program and again at the conclusion of CSUMS program and gain scores will be calculated. With the deeper knowledge in computation and mathematics, the participants are expected to take more high-level challenging courses during their junior and senior years. The evaluation team will calculate descriptive statistics and compare the participants' attitudes toward programming and the relevance of mathematics to solving real world problems as they enter the program and again at the end of the program. Participants will be surveyed in the fall semester for the perceived readiness for taking more challenging tasks in their studies along with the perceived impact on their learning in more advanced courses. Both qualitative and quantitative data will be collected for evaluation. Throughout the year, data will be collected from questionnaires, surveys, structured interviews, observations (indirect methods) and counts of substantive activities, e.g. written and oral assignments (direct methods). The data will be coded and analyzed by the evaluator. Data analysis will be an ongoing process, generating information to be provided to the appropriate stakeholders (PI, teachers, students, Advisory Board, NSF) on a timely basis.

To measure the impact of the CSUMS project on the undergraduate program in the Department of Mathematics, yearly statistics of the undergraduate enrollment, demographic data, high level courses taken by the juniors and seniors in the major for both CSUMS participants and non-CSUMS participants will also be collected, compared, and analyzed.

Formative reports that document ongoing evaluation activities will be prepared as each semester of activities is completed and will be used to make project modifications. The final report will be a comprehensive review of the project activities and outcomes and will be completed within three months of the project termination. The table in Figure 2 illustrates the evaluation design. Each evaluation component developed will begin with an assessment of learning objectives using the Teaching Goals Assessment. A list of objectives will be developed including specific thinking skills, strategies of learning, specific content, problem solving abilities and career success skills. Overall, this evaluation seeks to answer needs that are both process and product oriented and will yield a wealth of information with significant formative and summative implication. In particular, the summative evaluation will add to the newly emerging research base on standards focused project based learning.

In addition to assessment of pedagogical and content issues, as an evaluation of the outcome of the overall project, a study will be conducted on how the students career choices have been impacted by CSUMS. This study will do the following:

1. Track how much of our CSUMS content makes it into the core curriculum of undergraduate program of study via course revisions/additions
2. Track the impact of computer vision and image sciences as a topic for attracting math undergraduate majors to pursue advanced studies in computational sciences, by surveying graduated CSUMS participants
3. Track the participants who works in the industries that requires both computation and mathematics skills and solicit employer feedback to determine how well prepared our students are for research and development roles in these industries.
4. We will keep track of students after they complete CSUMS program to determine how many participants are admitted to graduate schools, how many of those are getting fellowships, how many of those admitted are completing M.S., and Ph.D. degrees.
5. We will carry out exit interviews after students have successfully completed their CSUMS experience. We will use information from these exit interviews to improve the preparation of new students for the tasks ahead.

8 Dissemination

We will create a dedicated CSUMS Resource Website, which will publicize recruitment, the curriculum development, research topics, and the project outcomes. Additionally, at the end of this project, we will summarize our experience in a paper and submit it to journals in Mathematics, Education and Computer Science and Engineering Education. Through our teacher's training program (ITEST), we will have close contact with local high school teachers and we will visit high schools (as well as other interested colleges and universities) and give talks about CSUMS.

9 Results From Prior NSF Grants

We have received NSF REU Site grants for the past 18 years. Approximately **one hundred and eighty** undergraduate students from several institutions in Florida (e.g., Rollins College, Stetson University, Eckerd College, UCF, USF, FIT, UF) and other states (e.g., California, Connecticut, New York, Michigan, Wisconsin, Georgia, South Dakota), have participated in this program. These undergraduates have co-authored more than **seventy** research papers (See references from [54] onwards). About **half** of these participants have gone to graduate schools, ten students have written Honors in the Major Theses, five participants are now faculty members at different Universities, and three participants have started their own companies.

Our model for REU has generated praise and interest among our colleagues. In 1990 NSF selected three top REU groups in the nation: Cornell, Arizona and **UCF**. The PI was invited to visit Washington with an undergraduate student and give a talk about REU. We received requests for a copy of our winning proposal from several Schools in particular predominantly undergraduate institutions and we have made our proposal available through the web page [4]. In June 1997, we presented our REU model and experience in mentoring undergraduate students in the *IEEE Workshop on Undergraduate Education & Image Computation*, with a large number of participants from undergraduate institutions in attendance, who were supported by NSF travel grants.