A Novel Brainstorming Pedagogy to Mobilize Pico/Nano/Micro-Satellite (PNMSat) Engineering Research and Education in India

Dr. Sharanabasaweshwara Asundi, Tuskegee University

Sharanabasaweshwara Asundi, a native of INDIA, is a Ph.D. from University of Florida working as an Assistant Professor in the Department of Aerospace Science Engineering at Tuskegee University (TU). Currently, he is engaged in several teaching and research activities, largely focused around initiating a Small Satellite Program at Tuskegee University. As part of the effort, he has engaged in research collaboration with NASA Goddard as a Science Collaborator. Based on preliminary research conducted at NASA, Dr. Asundi has been awarded grants by the U.S. Air Force and National Science Foundation to set up a Magnet Coil Test Facility and research Magnetic Mapping of Pico/Nano/Micro-Satellites. Through an award from Rockwell Collins, Dr. Asundi has set up an Amateur Radio Station at TU to track satellites. Dr. Asundi teaches courses in Orbital Mechanics, Automatic Flight Controls, Satellite Design, among others. He is actively engaged in collaboration with academic institutions in India. As part of invited visits, Dr. Asundi has conducted several short courses and workshops in Systems Engineering Based Design of PNMSats.

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Abstract
The article describes the outcome of activities to positively impact the careers of engineering graduates in India by engaging them in pico/nano/micro-satellite (PNMSat) engineering through a novel brainstorming pedagogy. The pedagogy, derived out of a systems engineering approach developed for the design and development of PNMSat/CubeSat missions, is used to teach a comprehensive course in PNMSat design engineering. The approach involves brainstorming the participants to conceive a PNMSat payload and teach the PNMSat bus design to accommodate the conceived payload. The approach and the comprehensive treatment of the material are the first of their kind in India in the field of small satellite design engineering. The article describes in detail the course contents, the novel approach and the results of the course assessments from three offerings – Summer 2015, Summer 2016 and Summer 2017. It presents the results of surveys conducted to assess the impact on the participants' awareness in PNMSat engineering, motivation to pursue diverse careers and fulfilling livelihoods. It's been observed that engineering institutions in India are keen to initiate a PNMSat program but have struggled to do so due to the lack of a systematic approach. The article provides an insight into addressing this problem and mobilizing a PNMSat program at an engineering institution in India.

Keywords
Systems Pedagogy, PNMSat/CubeSat Mission/Program, Engineering Education in India, Diverse Engineering Careers, Space Systems Engineering and Pedagogy

1. Introduction

There is a growing need in India to educate the youth as engineers, doctors, scientists, and most importantly, responsible citizens [1], [2], [3]. In particular, there is a growing need for educated aerospace engineers who can complement the untiring efforts of organizations like the Indian Space Research Organization (ISRO). Over the decades, ISRO has established itself as a premiere space organization and enabled India to be one of the elite nations to explore the frontiers of Mars and other space missions [4], [5], [6], [7]. However, the support system to enable ISRO in maintaining its superior standards and replenish its aging workforce is limited. In the past 2 decades, the information technology (IT) industry has had a paradigm changing impact on the engineering careers in India. Although, the engineering education system in India has accommodated an unprecedented diversity in its disciplines, the careers sought by graduates have largely revolved around IT [8]. In an effort to find a high paying job, budding engineers have failed to seek fulfilling careers, enrich their livelihoods and contribute towards the nation.

For the last three summers (2015, 2016, 2017), the author has been visiting academic institutions across India to conduct courses, workshops, and awareness programs in the field of pico/nano/micro-satellite (PNMSat) engineering. The underlying intent of these visits has largely been to motivate individuals, particularly women, to seek diverse careers. The vision of this engagement has been to initiate PNMSat programs at these institutions and motivate research activities in STEM disciplines. This article describes a novel approach used to conduct a short course, “Satellite Design”, and assesses its impact through results from a survey. The novelty of the approach was to brainstorm a potential PNMSat payload among the participants and teach PNMSat design engineering to accommodate such a payload. The approach and the relatively comprehensive treatment of PNMSat engineering may be the first of its kind in engineering education in India and particularly so in the field of satellite engineering. The course was first offered at PES University [9] in Summer ‘15 [10] and the participants included students, research associates, faculty and space enthusiasts from across India. Based on the participants' feedback, the course was improved and offered again in Summer ‘16 and Summer ‘17. A distinguishing feature of the Summer ’16 and ‘17 offerings was the use of a classroom satellite kit from EyasSat [11], [12]. Insights into these offerings, their impact on the participants, attitude towards their career and the general awareness in satellite design are presented in this article.

2. Course Agenda and Purpose

The overarching goal of the course has been to introduce PNMSat/CubeSat [13], [14], [15] mission design in a systems engineering framework and foster leadership development among participants. The objectives of the course catered towards – (i) Introducing Systems Engineering for PNMSats, (ii) Engage students in the design of a PNMSat with a novel payload and (iii) Foster leadership and team development through learning stages. The course agenda consisted of 3 phases and the following outcomes were sought for assessing the success of the course.

1. Demonstrate a basic understanding of PNMSats and their purpose.
2. Demonstrate an understanding of systems engineering and its need for the design and development of PNMSats.
3. Envision a project life cycle of a PNMSat mission and plan to be successful.
4. Demonstrate an understanding of the various subsystems of a satellite system
5. Demonstrate an understanding of the role of leadership in team building and executing successful missions.
6. Demonstrate an understanding of learning stages and its implication for PNMSat missions.

Phase I (Week 1)

The focus of Phase I was to instill a sense of team among the participants and get an insight into the anatomy of PNMSats. The agenda for Phase I facilitated answers for:

1. Why am I attending this course?
2. What are PNMSats and are they really different from any other class of satellites?
3. What is systems engineering and why is it relevant to this course?
4. What does it entail to design, develop and launch a PNMSat?

Phase II (Week 2)

The focus of Phase II was to provide an overview of the anatomy of satellites and facilitate the participants to seek answers to the following questions:

1. What are the constituents of a PNMSat?
2. What is the role of the following subsystems of a PNMSat?
   a. Command & Data Handling System
   b. Electrical Power System
   c. Telemetry, Telecommand and Communication
   d. Attitude Determination and Control
   e. Orbit Design, Control and Ground Tracking System
   f. Structural and Thermal System
   g. Payload System
3. How do these subsystems integrate and form a PNMSat system?
4. How do I make sure my PNMSat will achieve its goal in space?
5. How do I launch my satellite if I put in the effort to build one?
6. What do I do once the satellite is launched and executed its intended goal?

Phase III (Week 3 & 4)
The focus of Phase III was to go through a PNMSat design exercise. The participants were divided into teams and were guided to go through a project life cycle for designing a PNMSat. The participants envisioned a PNMSat mission, captured the vision as a mission definition and went through a systems engineering process to design a PNMSat. The teams would use basic physics, mathematics and computer-based tools to achieve the goal.

3. Systems Pedagogy & Course Implementation

The course was planned and implemented with a systems pedagogy, largely based on the CubeSat Systems Engineering Approach [16], [17] developed as part of the research and involvement in a pico-satellite mission at University of Florida. The core of the systems pedagogy is to translate a space mission idea/concept/payload into basic building blocks. These basic building blocks and their design are the constituents of the course. A day-to-day breakdown of the course activities is captured in Table 1. As part of week 1, two days were dedicated to providing an overview of Orbital Mechanics concepts, methods and mathematics. One day of week 1 was dedicated to providing an overview of CubeSat systems engineering approach. The remainder of week 1 was utilized to provide an overview of the subsystems of a PNMSat. As part of hands on activity for week 1, participants were introduced to AGI's Systems Tool Kit [18], a software used for creating various orbit scenarios for space missions.

A significant motivation and objective of the course was to brainstorm participants to conceive novel space payloads. As part of week 2, 2-3 days were dedicated to brainstorming and a novel payload was identified for the remainder of the course. The systems engineering approach, subsystem design, payload design were discussed in the context of the conceived payload. The participants were divided into teams and each team was tasked with designing a subsystem.

During week 3, all participants were tasked to develop at least one entity, which would require them to interact with practically every other participant in the course to experience system integration. The entities developed by the teams included power budget, link budget, mass budget, CAD design of the PNMSat, software architecture, mission concept of operations, etc. As part of the final week, participants were given an opportunity to simulate their designs using software tools. Every team was required to prepare a design document and present it as a poster.

Table 1 - Day to Day Course Activities

	Activity Title	Activity Description
Week 1	Course overview, expectations, limitations, etc.	The first interaction will primarily focus on the course overview, scope, expectations, evaluation criteria and most importantly learning outcomes
	Orbital Mechanics overview	Kepler's Laws, Newton's Laws, conservation of linear momentum, angular momentum, total mechanical energy, orbital elements
	Satellite Subsystems overview	Overview of electrical power system (EPS), on-board computing (CDH), communications (TT&C), attitude determination & control (ADCS), structural and thermal (S&T), ground communication, payload systems
	Systems Engineering overview	PNMSat systems engineering approach, requirements flowdown, mission mapping, N2 chart, components, interfaces, tasks, mission profile, circuit schematics, power budgets, telemetry budgets, link budget, operating modes
	First week lab interaction	STK simulations of orbit scenarios, application of orbital mechanics, application of systems engineering for an example mission.
Week 2	Payload brainstorming	Second week will primarily focus on the preliminary design of a satellite bus (PNMSat mission) to support a novel payload, either proposed by the instructor or brainstormed with participants. The focus of Week 2 - Day 1 will be to discuss a novel payload for the remainder of the course.
	Mission specific implementation of the systems engineering	Identify mission statement/goal, mission objectives, mission requirements (allocated & derived), identification of basic building blocks, N2 chart, Mission profile, etc.
	Mission specific discussion of satellite subsystems	Mission specific discussions of EPS, CDH, TT&C, ADCS, S&T,
	Second week lab interaction	CAD design of PNMSat system (3U/6U), MATLAB/Octave design of ADCS, design of electrical schematics, power budgets, mission profile, overall software architecture, etc.
Week 3	Detail design of satellite subsystems	Third week will focus on the detail/mid-level design of subsystem level architecture, component-level selection, interface/protocol design, simulation & analysis. The focus of Week 2 will be used to provide an overview of the detail/mid-level design.
	Mission specific detail design of satellite subsystems-Part 1 Mission specific detail design of satellite subsystems-Part 2 Mission specific detail design of satellite subsystems-Part 3	Detail design of EPS (power generation, distribution, storage, monitoring PCB panels, etc.), CDH (software architecture, operating modes), TT&C (telemetry budget, antenna structure, stowing and deployment, link budget), ADCS (actuator design/selection, attitude sensor design/selection, control laws/algorithms, on-board models) S&T (payload specific CAD, chassis design to accommodate payload requirements, thermal provision), ground station (data uplink/downlink, link budget)
	Third week lab interaction	Detail design of PNMSat physical system layout (CAD tools), EPS (MS Excel, Visio, PCB tools), CDH (MS Visio, PCB tool), ADCS (MATLAB/Octave), TT&C
Week 4	Detail design of satellite subsystems	The final week of the course will focus on subsystem-level integration, simulation, analysis, creating test scenarios, design documents.
	Design simulation, analysis & documentation - Part 1 Design simulation, analysis & documentation - Part 2 Design simulation, analysis & documentation - Part 3	As part of EPS design simulation/analysis, the participants will learn to assess system performance during Sun & eclipse time for various angular rates, etc.; ADCS design simulation/analysis will include system stabilization, control, sensor emulation, etc.; TT&C design simulation/analysis will include antenna performance at various angular rates; preparation of design documents (EPS, CDH, TT&C, S&T, ADCS); design level integration (N2 chart, circuit schematics, interface schematics); poster/presentation of subsystem-level design & integration.
	Fourth week lab interaction	Consolidation of design, simulation & analysis of PNMSat subsystems; design documentation, test design/report, 3D printing of CAD model (based on availability); presentation/poster.

4. Course Assessment – First Offering (Summer 2015)

The first course offering was made in Summer 2015 (June 8th, 2015 - July 4th, 2015) and attended by ~30 participants. A majority (> 85%) of the participants for this offering were males. The course offering potentially being the first of its kind in India in the field of small satellite design engineering, needed to be assessed for its effectiveness and impact on the participants. After the conclusion of the course on July 4th, 2015 [19], a survey was conducted to assess the course and its impact. In the survey, the following questions were posed to the participants:

Set 1: Please indicate the level of effort you put in for the various aspects of the course:

- Level of Effort – Assignments
- Level of Effort – Design Reports
- Level of Effort – Poster
- Level of Effort – Overall Course

Set 2: Please indicate your level of awareness in Satellite Design before and after the course:

- Level of skill/knowledge at start of course
- Level of skill/knowledge at end of course
- Level of skill/knowledge required to complete course
- Contribution of course to your skill/knowledge

The scale used for recording the responses was from poor to excellent as shown in Figure 1 and Figure 2. As seen in the chart, ~90% of the students expressed significant benefit in the understanding of satellite design by participating in the course – i.e., ~90% of the students who had only fair or satisfactory knowledge of the material at the beginning of the course, expressed gaining very good or excellent knowledge in the field at the end of the course.

Figure 1 - Participant Level of Effort for Course (Summer '15)

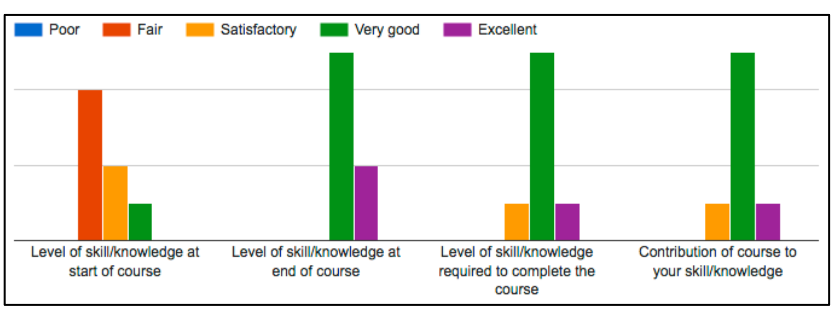

Figure 2. Level of Awareness Questions (Summer '15)

It was observed from the survey that the 10% of the students who expressed having very good knowledge at the beginning of the course were from the aerospace engineering background and even those students experienced benefit in attending the course. This course offering was the author's first experience teaching at a university, which is outside of the United States.

To assess the effectiveness of the instructor and the quality of the course content, 2 sets of questions were posed and responses recorded:

Set 3: Skill and responsiveness of the instructor

- Instructor was an effective lecturer/demonstrator
- Presentations were clear and organized
- Instructor stimulated student interest
- Instructor was available and helpful

Set 4: Course content

- Learning objectives were clear
- Course content was organized and well planned
- Course workload was appropriate
- Course organized to allow students to participate fully

It was very motivating to understand that all the participants (100%) either agreed or strongly agreed, as shown in Figure 3, that the instructor was effective in delivering the multidisciplinary content of the first such offering. However, the participants did indicate that the course needed to be more organized and planned for the next offering, as shown in Figure 4.

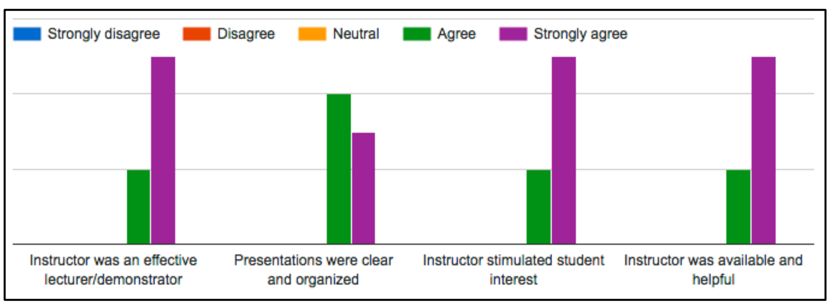

Figure 3. Instructor Effectives (Skill & Knowledge – Summer 2015)

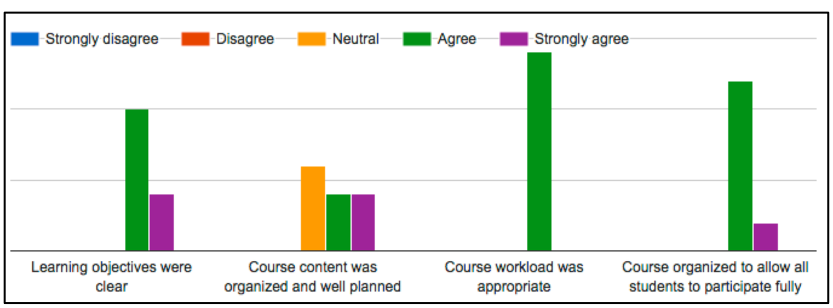

Figure 4. Course Content & Organization (Summer 2015)

The most critical evaluation component of the course was to understand if it had an impact in affecting the long-term career goals of the participants. Although, only a direct question (Did the course and instructor motivate the participant to seek a seek a career in their domain?) was posed to evaluate this understanding, it was evident (Figure 5) that more than 85% of the participants felt motivated to seek a career in their domain as a result of attending the course. Considering the larger purpose of the activity, the author felt redeemed looking at the overall response to this question. In the comments section, participants expressed joy in attending the course and learning about PNMSats in a short duration. The participants also, overwhelmingly, indicated that hands on training in such an offering was critical for increased value addition. Additionally, many expressed a desire to extend the duration of the course.

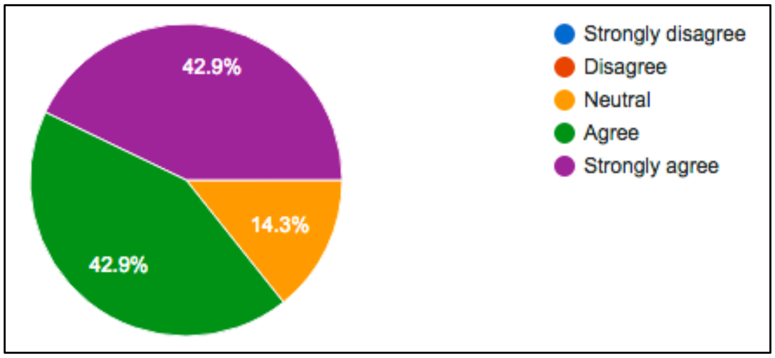

Figure 5. Course & Instructor's Impact on Participants' Careers (Summer 2015)

5. Course Improvement & Re-Assessment – Second Offering (Summer 2016)

Based on the evaluation of first offering and post interaction with course participants, a significant hands-on component was added to the second offering in Summer 2016 (June 13th, 2016 - July 13th, 2016) [20]. This particular course offering saw an increase in the overall participation and an overwhelming increase in female participants (> 65%). As part of the hands-on training, the course was taught using a classroom satellite kit, shown in Figure 6, from EyasSat (Barnhart et al., 2005, November; Burditt, 2016). The classroom satellite kit, which has all the subsystems of a typical satellite, is a boon for learning space systems engineering. It is designed and built as a modular system, which allows a learner to experience the various subsystems of a typical satellite. A comprehensive manual is developed with basic inspection, unit, integrated, and system level testing activities. The system is designed with sensors and actuators to teach spacecraft attitude determination and control, which is often a challenging system for beginners. Through the use of this kit, the participants would gain training/experience with satellite tracking, telemetry communication and an understanding of telecommand operation. To accommodate the use of the classroom satellite kit, the Friday lab sessions were extended. Participants would be divided into groups and each group would have an opportunity to assemble, disassemble and operate the classroom satellite in the ESD laboratory at PES University. In the ESD lab, the participants put on ESD sensitive coats, shoes, gloves and got to experience being a space systems engineer. It is important to mention here that along with the classroom satellite kit, basic ham radio equipment along with packet radio adapters, shown in Figure 6, were also used to educate the participants in the methods of radio communication. The three components proved to be a significant value addition to the Summer 2016 offering.

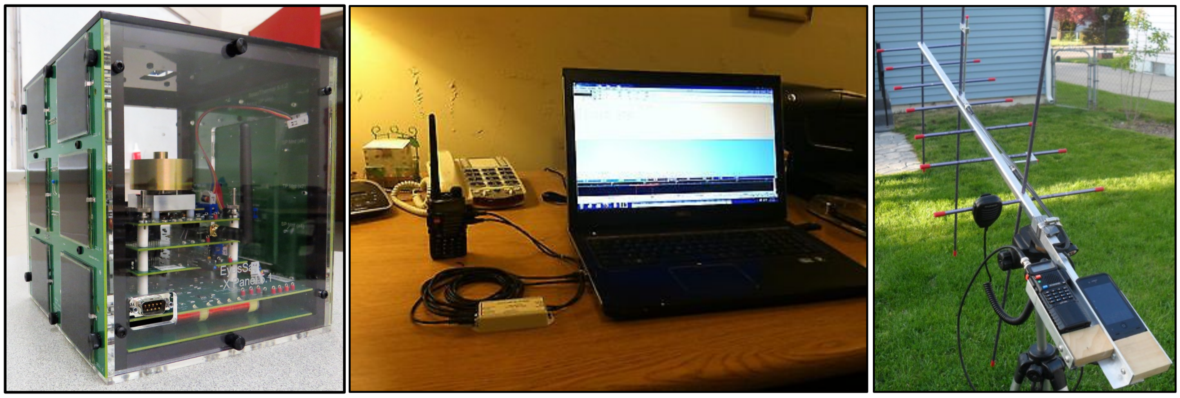

Figure 6 - EyasSat Classroom Satellite Kit, Packet Radio Communication, Handheld Radio and Antenna (Portable Radio Communication)

Similar to the Summer '15 offering, the participants' awareness and effort were evaluated with the above questions for which the responses are shown in Figure 7 and Figure 8. It is important to mention here that, although, Summer '15 participants expressed satisfaction in completing assignments, weekly reports were adopted for Summer '16 offering as a more relevant means to understand engagement and effort on daily/weekly basis. From the results of the survey, it was unsettling to know that the participants were barely satisfied with their effort in preparing weekly reports. However, a majority of them expressed satisfactory or more than satisfactory engagement with regards to preparing design reports/poster and the overall course.

Figure 7 - Participant Level of Effort for Course (Summer '16)

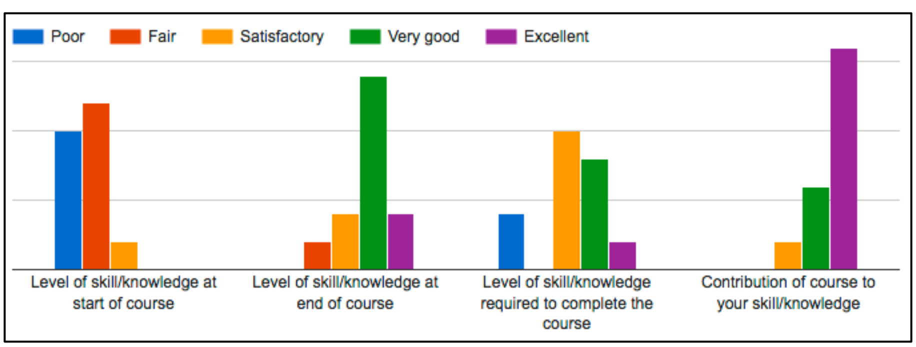

Figure 8. Level of Awareness Questions (Summer '16)

With regards to the level of awareness, it was evident that the course continued to increase the level of awareness among participants – i.e., at least 75% of the participants either agreed or strongly agreed that their skill & knowledge in the field of satellite design had significantly increased as a result of attending the course. Similar to the previous offering, the effectiveness of the course and instructor were overall a high positive as shown in Figure 9 and Figure 10. In spite of the increased attention paid to course planning, it seemed like participants still felt the need for more organization and planning (**Error! Reference source not found.**). Although it was observed that the overall impact in motivating the participants to seek diverse careers was largely positive, a small percentage (~17%) of the participants strongly disagreed (Figure 11). However, the participants overwhelmingly indicated that the course was a value adding experience. Many participants noted that the hands on training using the EyasSat kit proved to be of high value. Similarly, the participants indicated that working on a payload, which was conceived as part of the course, gave a personalized touch to the course and motivated them to be more diligent and forthcoming in their approach & attitude. One participant mentioned that the course was a career-starter for himself and his batch-mates.

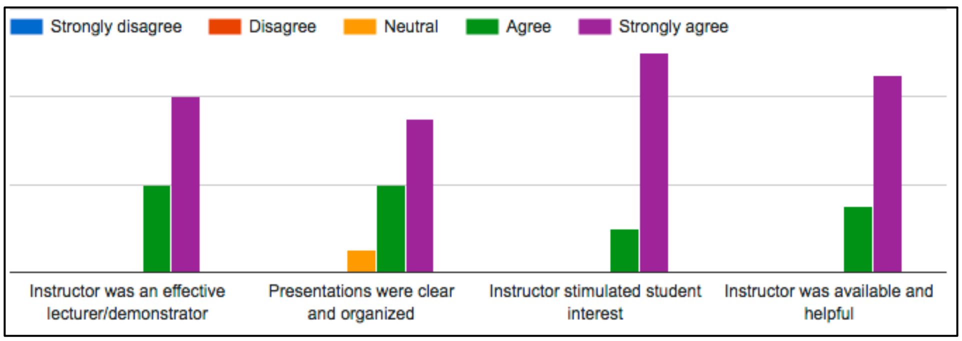

Figure 9. Instructor Effectives (Skill & Knowledge – Summer 2016)

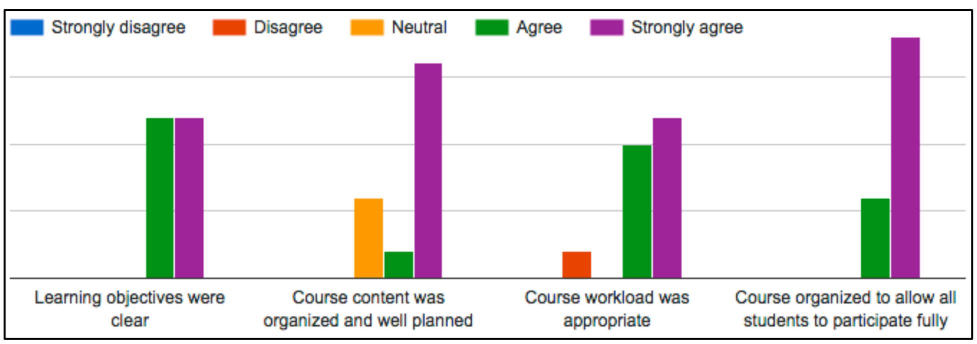

Figure 10. Course Content & Organization (Summer 2016)

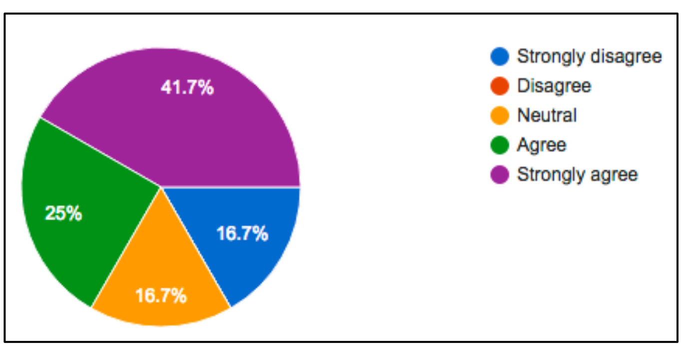

Figure 11. Course & Instructor's Impact on Participants' Careers (Summer 2016)

6. Course Improvement & Re-Assessment – Third Offering (Summer 2017)

The most recent offering of the course was in May-June 2017 (Summer '17). Based on the feedback provided through the surveys, the Summer '17 offering was altered to accommodate more interaction between the participants. As part of the weekly engagement, the instructor would interact and drive the discussion 4 out of 5 weekdays. One day of the week (Wednesday) was designated as a "Moderated Group Activity" day, where the participants would discuss among themselves and brainstorm ideas, solutions, and most importantly get to know each other. It is important to mention here that the underlying intent of this day was to foster leadership and a sense of camaraderie among the participants. Another important objective of this offering was to reach out to many more participants. The instructor was able to reach out to more than 120 participants during Summer '17, which included ~20 faculty members from major engineering institutions. Similar to the Summer '15 and '16, this offering was assessed with a set of questions as before. The responses to questions of Set 1, Set 2 are summarized in Figure 12, Figure 13.

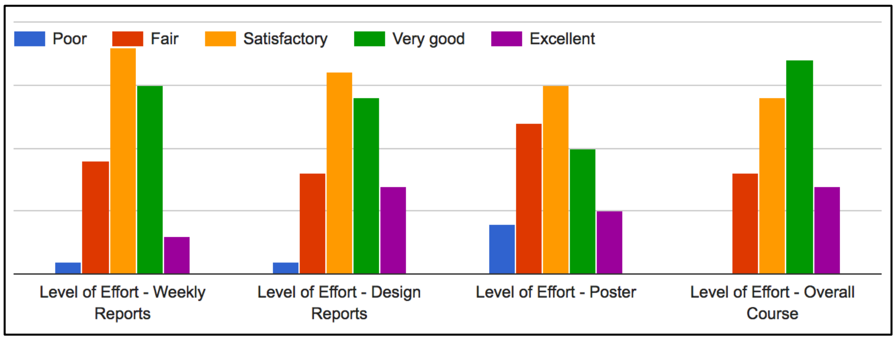

Figure 12 - Participant Level of Effort for Course (Summer '17)

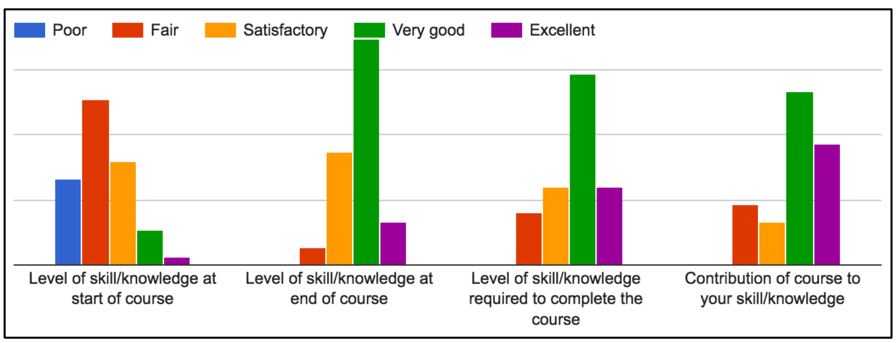

Figure 13. Level of Awareness Questions (Summer '17)

Although the participants expressed that their effort level in the overall course was mostly positive, their engagement in preparing weekly reports, design reports and posters were unsettling. From evaluating this aspect, it was observed that the course needed to be better organized to accommodate the increased participants. However, as is evident from Figure 13, the Summer 2017 course offering was successful in raising awareness among course participants. The responses to instructor's effectiveness were overwhelmingly positive (Figure 14) and the course content was also perceived as adequate (Figure 15). The overall impact of the course in influencing participants' careers was very positive (Figure 16).

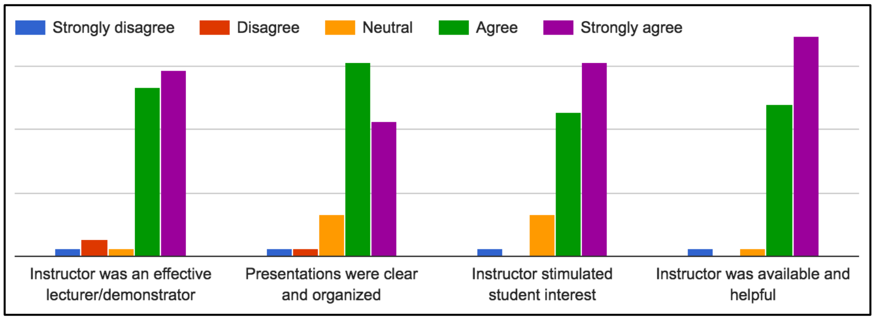

Figure 14. Instructor Effectives (Skill & Knowledge – Summer '17)

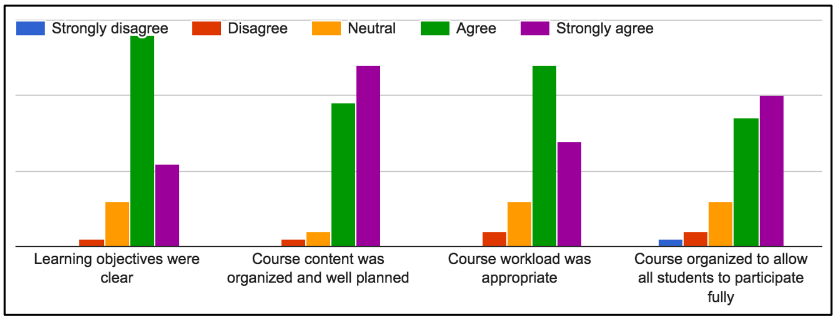

Figure 15. Course Content and Organization (Summer '17)

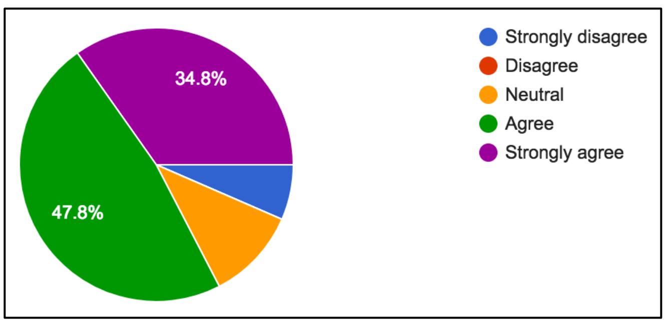

Figure 16. Course and Instructor's Impact on Participants' Careers (Summer '17)

7. Conclusion and Future Work

Academic institutions in India have shown keen interest in initiating PNMSat missions and programs but have had limited success due to the lack of resources and the absence of a pedagogical approach. The systems pedagogy adopted to teach satellite design has resulted in novel payload ideas for potential PNMSat missions and PNMSat programs. The brainstorming approach, which is novel for such a course, has given participants a sense of personal connection and enabled them to be more intentional. Faculty and student participants of the course have had the opportunity to explore the payload and through systems engineering, a preliminary to mid-level design of the various subsystems has been accomplished. It is important to reiterate here that this course may be the first of its kind in India to offer a comprehensive treatment of small satellite design engineering in a single classroom setup. An international collaboration is established between Tuskegee University (Tuskegee, USA), PES University (Bengaluru, INDIA), Siddaganga Institute of Technology (Tumkur, India). Although collaborations have been established with long-term vision, the following achievements are noteworthy:

1. A provisional patent has been secured by PES University for a matured version of the payload conceived as part of the Summer ’16 offering.
2. Two articles [21], [22] related to the payload conceived as part of the offerings are published in the proceedings of the AIAA SPACE ’17 Forum. The articles are authored by faculty and students of both collaborating institutions.
3. One article [23] related to the payload conceived as part of the Summer ’16 offering was presented at the International Astronautical Congress in Adelaide, Australia and published as part of its proceedings.
4. The team engaged in maturing the above payload has won an award at the India Innovation Growth Programme (IIGP) 2.0. As part of this award, the team has received Rs 10 Lakhs to further develop the payload.

Figure 17. PES University Team Receiving the IIGP 2.0 Award

5. Several students have conducted their final year projects related to the payloads developed as part of the course.
6. Several students have graduated with flying colors and are actively seeking graduate school admissions at both Indian and international universities.
7. A handful of them have already secured admissions at esteemed institutions across the globe.

The author is streamlining the course for an online offering with an on-site technician/instructor facilitating the lab sessions. It was observed that although there are a host of references for preparing the course material, a single textbook, which will enable the participants to be focused, is required. The author is preparing such a reference, particularly focused on PNMSat design engineering through the CubeSat systems engineering framework and working towards publishing it through a similar medium.

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