Comprehensive Research Experience for Undergraduates

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The Survey Research and Curricular Assessment unit coordinates campus wide survey research to assess student satisfaction, document student learning, and provide data for UCLA's academic program reviews coordinated by the Academic Senate. This work includes primary responsibility for developing and administering the Senior Survey to over 8,000 graduating seniors annually in the College of Letters and Science, the School of Arts and Architecture, and the School of Theater, Film, and Television. The unit also provides ongoing assessment support for academic programs within the Division of Undergraduate Education including those in areas related to general education programs, honors education, undergraduate seminars, transfer students, community learning opportunities, and undergraduate research education. Finally, the unit collaborates with faculty across campus to develop and implement curricular assessment components of funded grant projects.

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Abstract

The Research Experience for Undergraduates (REU) has been shown to positively influence the academic and professional performance of participants. The development of such programs has not been uniform throughout the past few decades. Nonetheless, hallmark characteristics are common between successful programs, which include: 1) meaningful research experience; 2) challenging yet welcoming environment with proper social network; 3) mentorship by faculty members and graduate students; and 4) well-rounded experience through supplemental workshops and seminars. Considering previous research, the Translational Application of Nanoscale Multiferroic Systems (TANMS) research center designed, implemented and assessed a comprehensive REU program to engage students in research during both the academic year and summer months. TANMS's REU is an eight-week research experience for undergraduates from multiple 4-year universities and community colleges. The program components include research in one of TANMS laboratories, seminars on ethics and diversity, workshops on entrepreneurship, and social events. These activities are woven into an experience to instill sixteen specific skills that were grouped into five core categories: I) communication (2 skills); II) engineering success (2 skills); III) business and market savvy (3 skills); IV) technical (5 skills); and V) multicultural and interpersonal (4 skills). The inclusion of these skills was based on the objectives of National Science Foundation's REU and ERC programs, the 'Engineer 2020' report from the National Academy of Engineers, and the American Society of Mechanical Engineers 'Vision 2030' report. TANMS's Industry Advisory Board reviewed, approved, and ranked the relevance and importance of each skill. After each research experience, i.e. 8-week program, students completed electronic surveys and either in-person or phone interviews, which were administered by an independent evaluator. The assessment protocol was reviewed and approved by Institutional Review Boards on each campus. Results are based on a sample of 51 undergraduate students from the first two years of assessment (participation rates of 71.4% and 81.8%, respectively). Findings suggest substantial increase in students' engineering knowledge and skills, with the overwhelming majority of participants indicating that they were "Satisfied or Very Satisfied" with TANMS REU program.

Introduction and background

Engineering and scientific research is the bloodline to improve and maintain the global competitiveness of the United States. Traditionally, the throughput of research is accomplished by academic faculty and postgraduate students. However, in the past few decades, there has been a keen effort to engage undergraduate and community college students in research to help advance the-state-of-the-art and to create a sustainable pipeline to graduate schools. Moreover, the shift in the demographics, based on recent census data, calls for the need to diversify the workforce by attracting and training underrepresented minority groups into engineering and science. Thus, the involvement of undergraduates in research has been supported by federal, state and local governments as well as by industry, since the shortage of domestic and diverse students in graduate school pipeline threatens the economic and technological advances of the United States. For example, the program highlighted in this paper is supported by the National Science Foundation, which mandates the expansion of: "*student participation in all kinds of research – both disciplinary and interdisciplinary – encompassing efforts by individual investigators, groups, centers, national facilities, and others"* [1]. Therefore, the goal is the integration of research and education to provide students superior undergraduate education [1]. In addition to NSF efforts, universities have long recognized the importance of training students in research early in their academic careers as doing so fosters academic preparation and motivation to attend graduate school [2]. Towards those ends, and considering the demographic composition of engineering and other technical fields compared to the United States at large, universities have created educational centers and programs to increase the participation of undergraduates—particularly underrepresented minority (URM) groups and women—in scientific research.

The REU described in this paper is designed based on research of best practices as well as the Center's prior experience to draw and retain undergraduates (emphasizing URM and women) in Science, Technology, Engineering and Mathematics (STEM) education and careers. Additionally, the program is aligned with the Center's strategic education focus: "*to develop the next generation of diverse and creative engineers to lead the new, global industry based upon innovative multiferroics technologies.*" Prior research in existing and successful minority programs such as Minority Engineering Program [2] and Meyerhoff Program at University of Maryland Baltimore County [3–5] suggests that the Center's REU program design is based on strong scientific foundations and poised to positively impact undergraduate educational experience while diversifying the future workforce.

Specifically, the Minority Engineering Program (MEP) was successful in increasing the retention rate of African-Americans and Mexican-Americans students in engineering more than twofold in comparison to retention rate of students from the same ethnic groups who were not involved in MEP over the same period [2]. MEP has five important objectives, which enabled it to achieve such remarkable results. The MEP objectives are: Community Building, Academic Survival Skills, Personal Development, Professional Development, and Integration into College and University [3–5]. The MEP initiative was established in the early 1970s in response to a challenge set forth by the industry "to take bold, innovative, all-out action to increase the supply of minority engineering graduate by 10- or 15-fold, and to get it done within the decade" [6]. Nonetheless four decades later, our nation's higher education institutes have largely failed to deliver an innovative solution to this challenge. The REU program reported herein is offering a path-forward to address this problem.

Interestingly, the Meyerhoff program, established almost a decade after MEP, has analogous objectives to MEP, which are: Academic and social integration, Knowledge and skill development, Support and motivation, and Monitoring and advising. Their approach to achieve these objectives consists of five-step plan: 1) recruiting a substantial pool of high-achieving minority students with interests in math and science who are most likely to be retained in the scientific pipeline; 2) offering merit-based financial support; 3) providing an orientation program for incoming freshmen; 4) recruiting the most active research faculty to work with the students (it takes a scientist to train a scientist); and 5) involving the students in scientific research projects as early as possible, so that they can be engaged through the excitement of discovery [3–5]. The similarities between the two programs suggest the importance of their objectives and approach in the design and implementation of any URM-based program.

Additionally, over the past three decades, many studies have investigated the structure and impact of engaging undergraduate students in meaningful and rewarding research experiences. Some studies reported on the effectiveness of such research programs on attracting underrepresented and underserved minorities as well as women to attain STEM undergraduate and graduate degrees. These studies provided evidence of increased interest in the specific discipline in which students performed their research [7–11], increased grit to continue their degrees [8,12,13], improved research skills [7–9,14], improved overall skills [8,9,14,15], and increased likelihood of pursuing graduate school in STEM [7–9,14,15]. It is important to note that characteristics common to the REU experiences studied in the above research are: 1) meaningful research project; 2) challenging yet welcoming environment with proper social network; 3) mentorship by faculty members as well as graduate students; and 4) well-rounded experience through supplemental seminars and workshops. It is also worth noting that these characteristics are analogous to those stated above for MEP and Meyerhoff programs [2–5]. Other research has focused on the impact of REU sites as well as other research experiences on underrepresented minority students and women [16–24]. For these groups, connecting the research experience to societal implications and promoting positive connections between students and the research community proved important [25]. In short, the impact of undergraduate research experience is tremendous on undergraduate students, graduate mentors, and faculty members.

In all, evidence-based practices from previous successful programs and published research indicate the importance of integration of undergraduates, specially underrepresented and underserved minority groups, in research to combat challenges to matriculation, retention, graduation, and enrollment in graduate school.

Approach

TANMS Engineering Research Center developed a paid eight week research experience for URM and non-URM undergraduate students, suitable for implementation during the academic year (semester or quarter systems) as well as during the summer months. The eight week duration was decided based on three competing demands. This REU was supported by National Science Foundation as part of Engineering Research Center program. First, the length of research experience must be sufficient to provide meaningful experience to students while allowing ample time for supplementary activities. Second, all participants throughout the Center must receive a consistent experience regardless of their academic setting (i.e., lab and campus). Finally, the mentorship structure, which includes a faculty member and a graduate student, requires substantial time commitment on the part of the mentors. Hence, eight weeks represent a balance between research duration, participant and mentors' commitments, and Center resources. Since the REU experience is offered year-round, the number of hours is tuned based on the availability of students during the academic year and summer. At present, students are required to commit 8-10 hours per week for research experiences during the academic year, while summer REU experiences are considered full-time commitments.

The program development process consisted of three stages: Identification of Skills, Program Elements, and Alignment and Validation.

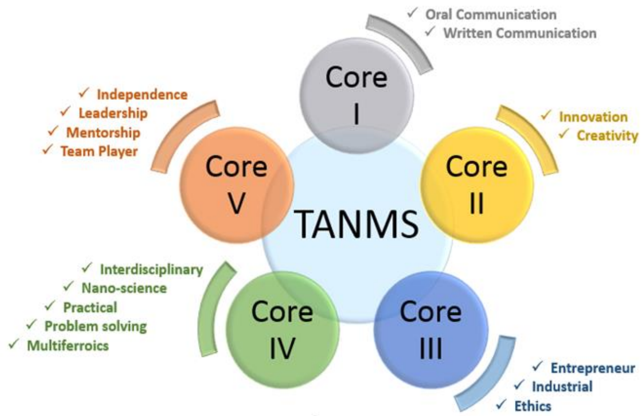

Figure 1: Research experience skill cores and skillset.

Identification of Skills

The first stage of program development comprised identification of skills, based on the NSF requirements, the Center's strategic focus, and needs of the engineering profession. First, NSF mandates that each ERC participant possess system-level skills that make them not only employable but also, and more importantly, effective contributors in industrial or academic settings. Second, the Center vision is to revolutionize and further miniaturize electromagnetic devices based on strain-mediated electromagnetic coupling. This requires competency in multiferroic materials, nanoscale, and interdisciplinary skills and knowledge. Finally, engineering is a dynamic and continuously evolving profession that demands a specific set of skills. These skills were published in 2005 by the National Academy of Engineers in the 'Engineer of 2020' report [26,27]. By considering all these requirements (i.e., NSF, Center vision, and profession), the Center identified sixteen skills and organized them into five cores. The skill cores are: I. Communication, II. Engineering Success, III. Business and Marketplace Savvy, IV. Technical Expertise, and V. Multicultural Interpersonal. Figure 1 shows the Center's five cores and associated skills. The definition of each skill is included in Appendix A.

Program Elements

As discussed in the previous section, a well-balanced research experience must include professional development activities, signficant research projects, and clear deliverables. Figure 2 shows the five elements of the undergraduate research program. First, meaningful research is the foundation of the Center's REU program, in which a group of approximately three students work under the mentorship of a faculty member and a gradauate student or a postdoctoral fellow. The deliverables and expectations are usually discussed with students during the program orientation and throughout the first week. They are also published on the program website, with clearly communicated deadlines, and always accessible to students electronically. The topics of research are in the general area of multiferroics (Skill Core IV) in any of Center's five technical thrusts: Memory, Antenna, Motor, Modeling, and Materials. Here, we highlight two important aspects of the first program element, i.e. research. The research project is related to the overall mission of the Center – to ensure that research is meaningful and with technological, economic, and societal impacts. Mentorship is an integral part of research, whereby undergraduate students work directly with faculty member and graduate student. This provides a welcoming work envorinment. In addition to research in the laboratory, several professional development seminars are designed and intergrated into the program, i.e., Program Element II, to instill industrial and interpersonal skills. The seminars' delivery methods differ based on the topic. For example, while the engineering ethics seminar consists of short pre-recorded videos that are followed by evalaution and discussion questions, the diversity seminar is interactive and broadcasted live to satellite locations. Regardless of the method of delivery, the Center strives to ensure that every participant has the same curricular experience.

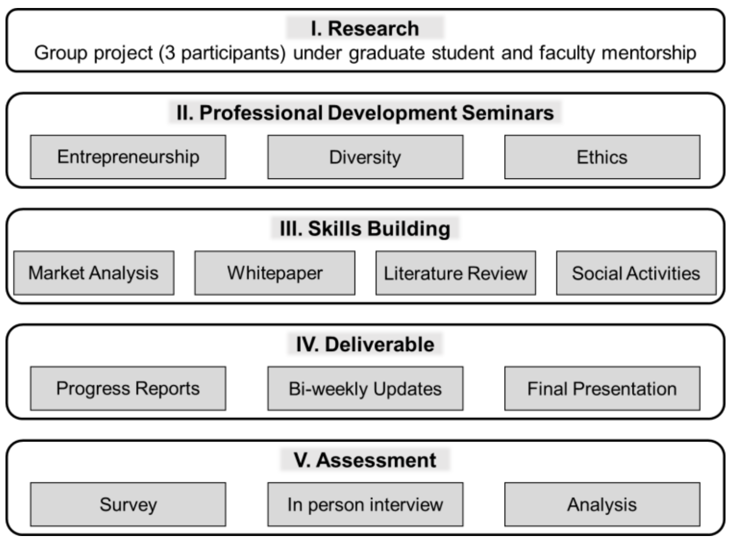

Figure 2: TANMS REU program elements

The third element in the REU experience is the skill building exercises, which were designed to instill entrepreneurial skills (e.g., market analysis), written communication (such as through writing a whitepaper and literature review), and independence (the aforementioned exercises are done individually) as well as social skills. Skill building exercises are assigned on an individual basis because they require substantial time, and are thus more conveniently completed outside of the laboratory. The Center created a guideline for the market analysis in the form of a questionnaire since most undergraduate engineering and science students have limited or no knowledge about business transactions. Other guidelines were also distributed to all participants to help with writing a whitepaper or literature review. In addition, students discussed these activities with each other and their mentors. Finally, regular in-person or remote social interactions between participants create the sense of community, which enhances the experience for all students.

In their assessment of the REU researchers used a mixed method, "multi-prong" approach to allow for more nuanced understanding of outcomes and program implementation, which could then be communicated to administrators in order to inform program development and modification. Assessment components were designed to measure key outcomes, i.e., ERC Core Skills. Data sources included electronic surveys, interviews, and application information as provided by TANMS. In order to maximize participation rates, tablet computers were used to administer surveys to students who could be physically available for assessment either at the assessment team's office or at a TANMS facility. Off-site assessment was conducted via online survey and phone interview. For either in-person or remote assessment, surveys were administered prior to the semi-structured interviews to help participants anchor responses in their reflections on their program experiences. For quantitative survey data, findings are based on descriptive analyses and corresponding statistical tests (e.g., z-test, t-test). Interview and qualitative survey responses were analyzed using both inductive and deductive coding. Additionally, analysis included comparison of REU and mentor responses in order to triangulate general themes and understand participants' experiences in the context of these different perspectives. Table 1 presents a summary of themes addressed by each data source for both undergraduate and graduate student participants.

Table 1: Assessment framework (*Denotes formative assessment component (vs. summative only))

Data Source	REU Themes	Grad/Post-Doc Themes
Exit Survey via tablet or email link	• Exposure to engineering content & research* • Engineering commitment & identity* • Peer & mentor experiences* • Mentor & advisor relationships* • Entrepreneurship* • Satisfaction*	•Mentorship experience* •REU gains* •Future plans •TANMS understanding* •Industry/ entrepreneurship* •Satisfaction*
Interview	• Activities overview* • Plans to return* • Formative feedback*	•TANMS ecosystem* •Mentorship strategies* •Formative feedback*
Existing data (TANMS database)	• Demographics* • GPA • Lab focus	•Demographics* •Lab focus

Alignment and Validation

Once the desired skills were identified (Figure 1) and program elements were designed (Figure 2), a formal mapping between each skill and associated was completed as shown in Table 2. This map shows that each program element addresses one or more specific skills (out of sixteen) and thus one or multiple cores (out of five). It is important to note that while a program element may be associated with a skill core, it does not necessarily address every skill within that core. For example, the professional development seminars are mapped to Business and Marketplace Savvy (Core III), but it is only associated with the Ethics skill. Aligning ERC cores, specific skills, and REU program elements is important to ensure that participants receive equal opportunity to develop each skill from one cohort to another and to facilitate the design and implementation of the assessment (see Table 1 for mapping between assessment component, program elements, and skills).

The final step in the program design in our approach was the validation that the desired skillsets are truly aligned with industry expectations. This was done by through collaboration with Center's Industry Advisory Board (IAB) who reviewed and rated each skill with regard to its importance to the field. The IAB feedback is shown in Table 2. In addition to quantifiably rating each skill as 'Must-have', "Important', 'Very Important', or 'Most Critical', the Board provided feedback about the industry perspective on a given skill. For example, the IAB rated creativity and innovation as 'Very Important' and indicated such skills are difficult to instill and associate with strong technical knowledge.

Table 2: Alignment of skills, program elements, and assessment components (§see Figure 2 for element numbers, *IAB indicated these skills are strongly dependent on technical knowledge)

Core Skills	skill Set	Program Element§	IAB Feedback	Assessment Components
I. Communication	I.1 Written Communication	I, III, IV	Very important	Survey questions
	I.2 Oral Communication	I, III, IV	Very important	Survey questions
II. Engineering Success	II.1 Innovation	I, II	Very important*	Survey questions
	II.2 Creativity	I, II	Very important*	Survey questions
III. Business and Marketplace Savvy	III.1 Entrepreneur	III	Important	Survey questions
	III.2 Industry	III	Important	Survey questions
	III.3 Ethics	II, III	Must-have	Survey questions
IV. Technical Expertise	IV.1 Nano-Science	I, III	Important to XYZ	Survey questions
	IV.2 Interdisciplinary	I, III	Most critical	Survey questions , interview
	IV.3 Practical	I, II, III, IV	Must-have	Survey questions
	IV.4 Problem Solving	I, II, III, IV	Must-have	Survey questions
	IV.5 Multiferroics	I	Important to XYZ	Survey questions
V. Multicultural Interpersonal Skills	V.1 Independence	I, III	Important	Survey questions
	V.2 Leadership	I, III	Important	Survey questions
	V.3 Team Player	I, IV	Most critical	Survey questions
	V. 4 Mentorship	I, IV	Important	Survey questions, interview

Results and Discussion

TANMS REU program was offered on several university campuses in California, New York and Massachusetts. The participants included students from the Center affiliated campus, other 4-year universities, and local community colleges. Students came from different STEM majors that included Mechanical Engineering, Chemical Engineering, Electrical Engineering, Materials Science, Chemistry, and Physics. In placing participants, two factors were considered: the student's topical interest and the availability of research opportunities in a specific laboratory. Students from community colleges were intentionally assigned to groups with at least one other community college student in order to provide a readily available social support system. The decision to provide these in-group supports was based on the expectation that community college students might not have the same level of skills, knowledge, and academic preparation as the undergraduate participants from 4-year universities, some of whom were already advanced in the aforementioned majors. In general, students worked in groups of three and on projects that are aligned with the overall center's competencies and research focus. Examples of the projects include: Modeling and Optimization of Strain Mediated Multiferoic Materials Systems, Study and Simulation of Eddy Current Reduction in Thin Film Ferromagnetic Material, Investigation of the Effect of Electric Field (VCMA) and Strain on Magnetic Memory Devices, Computational Design of Composite Multiferroics, Novel Multiferroic Heterostructures for Translational Compact and Power Efficient Voltage Tunable Devices, and Magnetic Simulations and Apparatus Design for Electrically Controlling Suspended Magnetic Microbeads. These efforts yielded multiple peer-reviewed journal papers that were coauthored by undergraduate students and their graduate mentors and faculty members.

Table 3 shows a summary of key assessment findings. Results are based on a sample of 51 undergraduate students from the first two years of assessment with participation rates of 71.4% and 81.8%, respectively. Approximately 40% of the sample were women and 60% were from underrepresented racial minority backgrounds. These results provide insight into the program evolution as well as the granularity of students' gains and satisfactions. The results show students have an overall positive experience and develop both their technical and nontechnical skills. For example, in Cohort 2, the large majority of participants were satisfied or very satisfied with the amount (85.7%) and quality (86.7%) of contact with faculty mentors, respectively. Participants' level of satisfaction in this regard increased by approximately 20 percentage points, as compared to the previous year. Additionally, 100% of the participants in both cohorts were satisfied or very satisfied with the interactions with their peers. The aforementioned statistics are strong indications that the Center is successful in placing students in welcoming group environments in which all participants can thrive, an important objective of any successful diversity focused program.

Table 3 also shows evidence of the program and assessment evolutions. Based on feedback from each assessment, the program evolves as the Center seeks to close gaps between the program expectations and goals, and students' experiences. Moreover, the Center strives to integrate best practices per new research. Concurrently, assessment instruments are updated to reflect the updated programs elements and activities. For example, 50% or more of all the participants in the Cohort 2 reported large or very large gains in their laboratory safety knowledge, openness to having their views challenged, openness to work with people with different beliefs, and openness to consider and discuss new research ideas; however these items were added to the assessment after review of Cohort 1's experiences (thus Table 3 does not include statistics for these items for Cohort 1).

Finally, while the majority of participants expressed overall satisfaction with the program in that it met or exceeded their expectation, formative assessment outcomes suggested specific ways in which the Center could improve the REU program. For example, students indicated that TANMS program prepared them well for new entrepreneurial endeavors; however the Center could improve upon the opportunities to interact with industry, both in quality and quantity. In response, the Center designed and deployed new industry activities, which include integration of undergraduate and graduate students in the bi-annual industry advisory board meetings, compilation and dissemination of a résumé book, and mock interviews with industry representatives. Preliminary indicators point to improvement in the interaction between the Center's students' population and the engineering industry, nonetheless, the measured impact is yet to be definitively assessed.

Table 3: Summary of key quantitative assessment findings, in percentages

Core	Outcome *(Response Measure)*	Cohort 1 (n=15)	Cohort 2 (n=36)
Communication	Research presentation *(large/very large gains)*	46.7	61.1
	Research presentation preparation *(large/very large gains)*	40.0	58.3
	Confidence in ability to understand engineering research *(large/very large gains)*	33.3	61.1
	Literature review skills *(large/very large gains)*	66.7	55.6
Engineering Success	Will succeed in engineering courses *(agree/strongly agree)*	100	97.2
	Will succeed in an engineering career *(agree/strongly agree)*	100	94.4
Business & Market Savvy	Level of preparation for developing new entrepreneurial endeavor was enhanced *(agree/strongly agree)*	26.7	88.3
Technical	Exposure to multiferroic materials development *(much/extensive)*	71.4	58.3
	Laboratory/materials safety knowledge *(large/very large)*	NA	50.0
Multicultural & Interpersonal	Openness to having their views challenged *(large/very large gains)*	NA	50.0
	Ability to work with individual with different beliefs *(large/very large gains)*	NA	55.6
	Working collaboratively to address common problem *(large/very large gains)*	73.3	66.7
	Openness to new ideas about research *(large/very large gains)*	NA	75.0
General Program Evaluation	TANMS experience exceeded expectations	66.7	69.4
	Amount of contact with faculty *(satisfied/very satisfied)*	66.7	85.7
	Quality of contact with faculty *(satisfied/very satisfied)*	66.7	88.6
	Amount and quality of contact with peers *(satisfied/very satisfied)*	100	100

Conclusion

In conclusion, the TANMS program is a well-balanced eight-week research experience for undergraduate students. Program elements are designed based on scientific research, best practices, and prior experience. The results of the program assessment show that overall the program is meeting or exceeding students' expectations, and students are placed in welcoming communities of scholarship and research. While, as with any program, there is room for improvement, the Center is continuously developing the program based on best practices and assessment outcomes with the intention of producing a reliable and sustainable means of diversifying the country's technical and academic workforce.

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Appendix A: Definition of skills

<u>*Core I – Communication*</u>
1- *Written Communication* – Students are expected to compile multiple written progress reports as well as a final report. Graduate students are expected to publish peer-reviewed journal papers as well as assist PIs with proposal writing.
2- *Oral Communication* – TANMS students are encourage to freely articulate themselves and their ideas and thoughts during meetings with PIs and mentors. Additionally, students are expected to deliver an oral technical presentations and posters.
<u>*Core II - Engineering Success*</u>
1- *Innovation* – Ability to execute new ideas in research, education, and industry with relevance (or relevancy) to multiferroics.
2- *Creativity* – Ability to synthesize new ideas on multiferroics. For example, students are able to suggest applications of multiferroics based on their research.
<u>*Core III – Business and Marketplace Savvy*</u>
1- *Entrepreneur* - Entrepreneurial mindset is discussed in multiple TANMS seminars. These seminars are recorded and archived. This mindset includes risk-taking as well as development of business ideas to meet customer needs and finding an engineered solution to meet the need.
2- *Industrial* – Interaction between students and Industry Advisory Board and Industrial Liaison through Industry-lead seminars and industry-mentorship program.
3- *Ethics* - Public safety is paramount focus in the engineering profession and thus each student is expected to be aware of the ethical implication of his/her design, system, or research. Student should know that ethical and legal are not the same that is a legal solution not necessary is an ethical solution and vice versa.
<u>*Core IV – Technical Expertise*</u>
1- *Nano-science* – TANMS research thrusts are focused on modeling, fabrication, and characterization of nanoscale homogenous or heterogeneous structures. For example, fabrication of thin-film piezoelectric or magnetostrictive materials.
2- *Interdisciplinary* - Integration of analytical strengths from two or more of scientific disciplines. TANMS is working on breaking new scientific grounds at the intersection of mechanical, electrical, chemical and physical sciences.
3- *Practical* – Students' ability to formulate reliable and achievable solutions rather than hypothetical ones.
4- *Problem Solving* – Students are able to clearly identify and understand the problem, devise a plan to implement most viable solution, execute the plan, and evaluate the results. In this process, students are expected to make decisions on viability of each solution considered and select the most suitable one.
5- *Multiferroics* – TANMS' core competency is multiferroics. Student should be engaged in a research project that is focused on modeling, synthesis and fabrication, and characterizations and applications of multiferroics structures and systems. The research outcome may or may not contribute to testbed design and fabrication but must be related to mutliferroics.
<u>*Core V – Multicultural Interpersonal Skills*</u>
1- *Independence* – Specifically, intellectual independence, which means that student is able to formulate viable solutions based on facts and engineering fundamental concepts then decide on the most suitable as well as scientifically and economically feasible solution. For example, student is able to decide between off-the-shelf versus manufactured in-house experimental setup.

2- *Leadership* - Individual contributor to research project and can lead the diverse and multicultural group to successful completion of the project.
3- *Team player* – Student works effectively in a multicultural multidiscipline group and contributes to tasks throughout the project. There are multiple roles within each team, which include: members who challenge the team to improve, members who get things done on time and on budget, members who can coordinate and lead, members who make sure the team work together, members who come up with creative and innovative solutions, and members who has specialized skills. Each student will assume a different role based on their personality and cultural background.
4- *Mentorship* – Mentorship is different from care-giving. TANMS strategic focus is to generate leaders in the industry and academia, which require students to understand and practice mentorship before graduation. An effective mentor should be: friendly with mentees, have realistic expectations, supportive, allow mentees to communicate and make choices, respectful, and responsible for building professional relationship with the mentees.