Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Very Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Vision: The vision of the proposed center (IMWEL) is to transform research in women's health through engineering innovations. The engineered system is a series of test beds in the following areas of women's health: preterm birth, pelvic floor disorders, and healthy aging. Undergirding the proposed engineering system is the concept the use of computational approaches, modeling, and bioinformatics to gain insight into the unique biomechanical properties of the tissues of the human pelvis. Health challenges related to the female pelvis affect a large segment of the female population, that research that leads to better understanding, diagnosis, and treatment is well aligned with the targeted societal impact. A center is necessary to realize the vision and to accelerate the development of devices informed by the separate areas of biomedical research involved.
Research:
Strengths
• The research is convergent.

Weaknesses
• It is not immediately clear to what extent mechanical forces play a critical role in the health challenges that are targeted, thus it is difficult to gage the likelihood that the research will lead to fundamental advances in diagnosis and treatment.

Infrastructure:
Strengths:
• The leadership team is very well qualified.
• The management structure and plan presented provide a clear and comprehensive plan to carry out the center activities.
• The proposed mechanisms to solicit feedback from all stakeholders are well thought out and will by effective.

Weaknesses:
No infrastructure weaknesses noted.

In the context of the five review elements, please

evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Engineering Workforce Development:
Strengths:
• The EWD plan includes students at several stages of the engineering pipeline, including middle school, high school, undergraduate and graduate students.
• Middle school interventions will be school based and will work with instructors at the intervention sites and will be adapted for each community.
• RET component will involve teachers in incorporating center related concepts into curriculum.

Weaknesses: None noted.

Diversity and Inclusion:
• The center institutions include a Hispanic-serving institution as well as other institutions that have a demonstrated commitment to diversity and inclusion as evidenced by existing grants and programs.
• The center will leverage existing infrastructure and pipeline programs for recruitment and retention of URM students.

Weaknesses
None noted.

ERC Integration:

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

The center has the potential for high societal impact. The team is appropriate to support the convergent research.

Summary Statement

This is a very good proposal that effectively communicates the research vision for the proposed ERC. The engineering workforce development and diversity and culture of inclusion plans leverage the strengths of the member institutions.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Very Good, Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Vision:

The vision of this Integrated Mechanobiology for Women's Health (IWWEL) engineering research center is designed to build systems of engineering devices to (1) monitor stretch of reproductive tissues, (2) promote muscle-to-bone healing and (3) measure the biomechanics of exercise. The team will utilize the field of biomechanics and mechanobiology to overcome women's health challenges. The focus on women's health is aligned with the targeted societal impact. The center appears necessary to realize the vision through impacting the society and training the next generation of engineers focused on a women-centered approach.

Research:
Strengths
+ There appear to be a vision for convergent research through the proposed center that would affect women's health.
The research Thrusts include multiscale theoretical mechanics and experimental, cellular and tissue mechanics. These research thrusts are complemented by the proposed testbeds that include Preterm Birth, Pelvic Floor Disorders, and Healthy Aging of cardiac and Musculoskeletal Systems. These testbeds appear appropriate for the proposed thrusts.
+ There is a strong desire to integrate the proposed test beds with the Thrusts to attempt to converge the central goal of the ERC.
+The proposed studies in the Preterm Birth and Pelvic Floor Testbeds are intriguing.
The approach for utilizing the proposed formulation of a chemo- degradation material model to describe fracture and Injury is quite novel.

Weaknesses:
-The plan to conduct finite element modeling of the pelvic floor organ incorporating microstructural information is interesting. However, there are little details on the precise approach that would identify model parameters, particularly those that will be tested in cellular and tissue level systems.
- Regarding proposed work in Thrust 4 on "BIG DATA and Bioinformatics," the team claims that their predictive models of preterm birth will uncover potential causations parameters of preterm birth such as age, genetics, stress, nutrition and hormones. However, the approach outlined in this proposal may only uncover association and therefore may not necessarily devise potential interventions.

- The presentation of the development plans of the proposed sensor technology would benefit from more details. For example, the team is planning to develop patch sensor to monitor the cervical remodeling remotely and provide alerts for urgent events, yet the developmental plans for such sensor is not discussed.
- Overall, the fundamental idea of the proposed center is of high risk. However, lack of details on many aspects of the experimental design do not provide sufficient information to provide concrete evidence of a potential high reward scientific discoveries and technological developments that could be uncovered by the proposed center.
-It would be helpful to outline a more clear timeline for the proposed plans for carrying out fundamental research, proof of concept of the proposed devices, sensor technology, preclinical evaluation.
-The proposed ideas of development of multiscale growth and remodeling biomechanical theories, and advancing quantitative imaging techniques and mechanobiology is quite an ambitious goal that would benefit from a clear roadmap. In addition, it would be helpful to discuss the plan of integrating such theories into the technology development aspects of the center.
-Given the potential of an ample of clinical data, a consideration of the inclusion of a bio-statistical core group may be helpful.

Infrastructure:

Strengths
+ The team possess expertise in biomechanics, mechanobiology, and psychology.
+ The ERC consists of a team of researchers from Columbia University (CU), East Carolina University (ECU), University of California, Irvine (UCI), and University of Pittsburgh (Pitt).
+ The proposed center has plans to initiate collaborative mechanisms across the participating institutions as well as with the industry partners.
+ The leadership and management structure consists of equal membership from each partner institution, and this suggests a true partnership.
+ Management plan includes an Engineering Innovation Advisory Board. The advisory board will provide feedback to translational research initiatives.
+ The inclusion of a Student Leadership Committee is appropriate.

Weaknesses:
-It would be helpful to discuss specific Plans to address potential loss of tenure track faculty members who are involved in the center.
-A consideration of a potential addition of physician scientists in ob/gyn disease would strengthen the translational research of the center.
- The development of a student leadership council to represent student interests from all partner institutions would be helpful.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Engineering Workforce Development:

Strength:
+ The team appears committed to implement evidence-based policies, and practices throughout diverse work force development.
+ The IMWEL team appears committed to train engineers, basic scientists, educators, students, and entrepreneurs at the nexus of biomechanics, mechanobiology, and women's health.
+ The PIs have encouraged women and underrepresented minorities-to pursue engineering for women's health.

Weaknesses:
-The development of a framework for positively affecting a curriculum in sensor technology would be helpful.
-The plan to generate curriculum modules that focus on tissues of the female reproductive system is not well-detailed.

Diversity and Culture of Inclusion:
Strengths:
The team appears committed to broadening participation of members of underrepresented groups including women, ethnic minorities, persons with disabilities, first generation in the engineering workforce.

The center is proposing to promote interdisciplinary collaborations between the different institutions' students through joint scheduled learning times, virtual lab tours, team research projects, participation in the Annual Meetings, and networking events.

Weaknesses:
The management plan would be strengthened through highlighting a clear responsibility for diversity and culture of inclusion.

Innovation Ecosystem:
Strengths
+ The team will develop an ecosystem that supports successfully translated devices for women's health.
+ The engagement of the center with industry could be expanded beyond those companies listed in this proposal.

Weaknesses:
The plans for community engagement could be strengthened.
Intellectual property and publication policies would need to be discussed in more details.
-The team envisions that by Year 10, the team will be able to develop an ecosystem that supports successfully translated devices for women's health. However, a clear pathway towards such ambitious goal would benefit from a more in-depth presentation.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

The center has a strong potential for high societal impact. If successful, the center could potentially support the development of clinically deployable devices to enhance healthcare for women. The strong team of investigators from the multiple institutions increases the level of enthusiasm for the center. The proposal would be strengthened by a more in-depth discussion of how the proposed center would integrate and implement research, workforce development, and innovation ecosystem development efforts together to achieve the center's vision. A more cohesive discussion of how these elements fit together would be helpful. The structure of the proposed strategy for engaging all relevant stakeholders over the life of the ERC could be strengthened. The team should expand the presentation of how the Center strong institutional commitment for all core partner institutions.

Summary Statement

The center is focused on a novel multiscale approach that utilizes biomechanics and mechanobiology to further our understanding of women's health. The center appears necessary to realize the vision through impacting the society and training of the next generation of engineers with a focus on a women-centered approach. Overall, the proposed central idea appears to be of high risk. However, lack of details on many aspects of the experimental design do not appear to provide sufficient information to support a potential high reward of scientific discoveries and technological developments that could devise potential interventions.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

The IMWEL proposal seeks to significantly advance the understanding of the tissues of the human female reproductive tract through developing a biomechanical model of tissues and mechanical stress. The team will create testbeds focused on preterm birth, pelvic floor disorders and healthy aging of the cardiac and musculoskeletal system. The vision is compelling--a detailed understanding of female reproductive tract tissues and biomechanical forces to create new models that may lead to new devices and, potentially, new disease prevention or treatment modalities. The need for convergent research in this area is clear. Research specific for women's health has been historically under-invested and the societal impacts, such as maternal death, are further magnified for BIPOC women due to health disparities.

The ERC approach to the problem of understanding female reproductive track and aging is compelling. The proposed research includes detailed understandings of micro-structures, tissues, organ structures and biomechanical stresses for adult females and during pregnancy, and then integrates those findings into models for the pelvis and cardiac functions. The proposal includes a plan for making those models available to the field and a strong EWG component.

IMWEL's participating faculty are well-qualified and the institutions and facilities are appropriate for the research proposed. The majority of the funds and leadership are at Columbia University, but there also seems to be a reasonable distribution of funds across the participating institutions. The proposal describes a sound design for organizational structure, management, and appropriate boards and committees. The IMWEL proposal describes a well thought out evaluation plan and experienced staff, although success metrics are not yet fully defined. The budget shows that 33% of the funds would be dedicated to research activities, a lower proportion as compared to other ERC proposals but it did not impact the review score.

Strengths:
- Compelling vision and approach. IMWEL proposes to address important gaps in understanding women's bodies that will serve to underpin potential new injury prevention and treatment modalities.
- I was convinced the modelling activities are highly complex and their plans to integrate biomechanics and mechanobiology seems like a strong value to the field.
Weaknesses
- 63% of the funds are designated for Columbia University and the other partners are <15% of the

funds each. This is a large disparity between the partners and creates a risk that the partnership will not be equitable. The research plan would be improved by more equitable distribution of resources, ideally with Columbia as <50%.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

The IMWEL proposal stands out for it's potential for broader impacts in the area of women's health and the EWG, DCI activities. The potential broader impact in the area of women's health was described above. The educational activities are, in part, designed to educate and normalize discussion of women's reproductive tracts and aging. The reduction of stigma for female pelvic floor disorders and new in-depth models of tissues and biomechanics would support an environment for increased research and product development interest.
The IMWEL program will combine the EWG and DCI efforts and focus on curriculum to develop familiarity and comfort with applying engineering principles to the female reproductive system. The proposal includes research experiences for teachers, research experiences for undergraduates and a "Workforce Intervention Curriculum" that is focused on women-centered design. Additionally, Univ of California, Irvine is an HSI-designated school, ECU has a track record of innovation in inclusive practices, and throughout the proposal the researchers demonstrated they were cognizant of the importance of inclusion of women and URMs in their research and training agendas. The research team may want to consider inclusion of organizations with a focus on black women's health specifically.
The program describes how EWG/DCI is integrated in the program and they will evaluate and hold themselves accountable for their EWG/DCI efforts--4 of the 5 major evaluation areas include EWG/DCI-related questions.
The data management plan includes making de-identified data and models publicly accessible through the Academic Commons, and open-sourcing software. Additionally, the researchers plan to make curriculum materials and student evaluation data publicly available. The testbeds will be available to commercial entities through an industrial affiliates membership program.
The innovation plan includes a pitch competition, innovation summits and the establishment of an industrial affiliates program. An IP plan was described but the details were insufficient to understand if they would enable industry interest in collaboration or commercialization, although that did not negatively impact the rating. IMWEL proposed an Innovation Advisory Board and hopefully they would advise on ways to ease licensing for potential industrial partners. The proposal includes a plan and has letters of support from start-ups and stakeholders in the innovation ecosystem.

Strengths
- There is high potential for positively impacting women's health. Research specific for women's health has been historically under-invested and the societal impacts, such as maternal death, are further magnified for BIPOC women due to health disparities. The educational activities are designed to reduce stigma about women's pelvic disorders and aging.
- The EWG an DCI plan is well integrated throughout the proposal
- The innovation plan is sound and industry engagement will be key to translating the findings of this program into products that improve women's health

- The Data Management Plan includes plans for making the data and models widely available and the testbeds available to industry through an industrial affiliates program.

Weaknesses:

- For the Community Impact Advisory Board, the proposal would be strengthened by inclusion of groups specifically focused on BIPOC Women's health

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Summary Statement

In summary, this is an excellent proposal and has a high likelihood of advancing the understanding and generating new models to support further health innovations for women. The research proposed is ambitious, appropriate as a multi-institution engineering center and focused on an area of high societal impact. The proposal does a good job of describing the faculty, institutions, research plans and organization structures and all are appropriate to achieve the goals of the program. Of particular note, this proposal has a well developed vision for EWG and a DCI ecosystem, and an emphasis on women-centered design.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Vision: The proposal envisions a center that will apply engineering innovations to overcome women's health challenges and develop a next generation of engineers focused on a women-centered approach. The proposal describes the center's engineered system as a system of technologies to restore and support the biomechanical form and function of the female reproductive, cardiac, and musculoskeletal physiology. The proposal articulates a clear concept that motivates the envisioned Center, namely that the female body has the ability to very dramatically modulate the mechanical properties of tissues and organs during pregnancy, childbirth, postpartum repair, and aging. This concept appears to have sufficient depth, breadth, and significance that a center-level effort could be developed around it. The proposed Center can have substantial societal impact. It will address specific issues within women's health that significantly impact the U.S. healthcare system, both in terms of health-care costs and in terms of patient well-being. The mechanobiological approach of the proposed center appears to be unique, at least at a center-level effort, and it could thus bring a very new perspective to issues of substantial societal significance. The proposal furthermore states that a center-level effort is necessary because a collection of smaller projects will be unable to provide the core structure and focus need to achieve the center's long-term objectives.

Having said that, the proposal would probably be strengthened if it articulated a more specific vision. It could more clearly explain what is meant by an engineered system of technologies and then explain how key system-level requirements flow backwards from clinical women's health needs to the underlying research at the Knowledge Base. And, the justification of a center-level effort would be more compelling if the proposal elaborated what key roadblocks face the diverse stakeholder community that are not being solved by current efforts from the general community both within and beyond the investigator team itself.

How strong and innovative is the proposed research?

Strengths:
- Tissues of the female pelvic area can undergo substantial mechanical deformation in a manner that differentiates these tissues from other components of the human body. The center's goal of better understanding these tissues offers much scientific potential. The combination of mechanics and

biology, coupled with an array of computational approaches, within the theme of pregnancy-related clinical complications thus appears to be a research focus with much opportunity, and the investigator team has research strength in this area.
- The team intends to concentrate on a set of three physiological testbeds that uniquely or disproportionately affect women. These are: (1) Preterm birth; (2) Pelvic-floor disorders; and (3) Healthy aging (of cardiovascular and musculoskeletal systems).
- There are four complementary Research Thrusts: (R1) Experimental cellular and tissue mechanics; (R2) Tissue and organ mechanobiology; (R3) Multiscale theoretical mechanics; and (R4) Mechanomics. These each address basic-level problems associated with women's health.

Weaknesses:
- The anticipated translation to more applied concepts of woman's health could be developed with more detail and vision. For example, it's not clear how the downstream integration of biomechanics into medical visits will be implemented. The proposal describes several devices that the center will develop (e.g. for Pre-term birth: bio-compatible wearable strain gauge, optical biopsy via OCT) and exercise interventions (Healthy aging: exercise protocols to enhance pelvic-floor strength), but these could be more clearly justified by an explicit stakeholder need (real or anticipated).
- The proposal would also be strengthened if it would more explicitly state a set of specific fundamental questions that confront each of the four Research Thrusts - this would speak to innovation and uniqueness - and how these are inter-related amongst the different thrusts (convergence).

Is the research convergent (interdependent)?

Strengths:
-The proposal describes a measure-model-make paradigm as a mechanism to organize the inter-dependent elements represented by three testbeds, the five enabling technologies, and the four research thrusts. This paradigm emphasizes the expectation that the center will produce devices that initially will help inform the basic research with new measurement information which in turn will enable new models of female anatomy/physiology across multiple length scales. This combination is then expected to enable the development of a set of applications-oriented devices able to, for example, predict pre-term or normal birth as well as incorporate biomechanics into medical visits.

Weaknesses:
- In the higher-level description of IMWEL research, the proposal discusses inter-dependence and convergence, but the more detailed descriptions of the four research thrusts and the five enabling technologies appear to be largely independent of each other.
- The three testbeds seem to be general topics within which research projects are categorized rather than specific problems around which the interdisciplinary engineering and science converge in a unified way.
- Similarly, the exemplar projects described within each of the four research thrusts appear to subdivide the three broader Testbeds into finer projects but do not clearly articulate convergence.

How does the proposed research benchmark in the current state-of-art and what is the likelihood that

the research will lead to significant fundamental advances, discoveries, and technological developments?

Strengths:
- At a high level, the proposal makes clear that the field of cell/tissue biomechanics has been predominantly focused on sports medicine and male aging. These are areas where mechanical deformations are relatively small compared to those associated with pregnancy.

Weaknesses:
- The descriptions of the four research thrusts could more explicitly summarize the state of the field and how that current state defines key challenges that must be overcome in order to advance the knowledge base.

How appropriate is the selection of research thrusts, projects, testbeds, and milestones?

Strengths:
- The four research thrusts and five enabling technologies appear to be very appropriate.

Weaknesses:
- The Preterm delivery and Pelvic-floor disorders testbeds focus on pregnancy-related issues, consistent with what appears to be the central focus of the proposed center. The Healthy Aging testbed addresses the ability of exercise to maintain and enhance women's health across an entire life span. As such, it seems that the Heathy Aging testbed risks promoting divergence rather than convergence.
- While the proposal certainly concentrates on women's health, this focus still seems very broad. Within women's health it would seem that there is a greater diversity of issues in addition to those addressed by the ERC IMWEL proposal (e.g. breast/uterine/cervical cancers; osteoporosis). It seems, though not explicitly stated, that the proposal focuses on its three testbeds (preterm birth; pelvic floor disorders; and healthy aging of cardiovascular and musculoskeletal systems) because of the common theme of mechanics within these, and this focus leaves open the question of how broadly impactful a mechano-biological approach can be for some of these other women's issues.

Is the idea high risk/high payoff?

Strengths:
- The IMWEL team includes a cadre of strong researchers with a history of research productivity and translation. One can anticipate that a center will amplify the team's ability to produce high-quality research outcomes. Raising the awareness of and academic foundations underlying issues of women's health within an engineering context has the potential for substantial impact and leadership in directing/redirecting the field.

Weaknesses:
- No overarching milestone, or set of milestones, is provided against which one could measure success

of the overall center concept. Instead success appears more likely to be incremental within the confines of the various research thrusts.

Infrastructure:

How well qualified is the leadership team?

Strengths:
- The leadership team appears to be satisfactory. Fig. 3, which illustrates graphically the leadership team, is helpful.

Weaknesses: None.

How well does the proposal present an appropriate and compelling management structure and plan to carry out Center activities?

Strengths:
- The center describes a hierarchy of committees - the Executive Committee, the Council of Deans, the STEEM Integration Committee, the Engineering Advisory Board, the Student Leadership Committee, and the Community Impact Advisory Board - that will provide oversight of various center elements. Notably, the center will involve the Team Scholarship Acceleration Lab at UC Irvine (TSAL) to deliver convergence science training and consultation with focused audits at the end of years 2-4.

Weaknesses: None

Are effective mechanisms to gather feedback from appropriate stakeholders in place, including advisory boards and external committees?

Strengths:
- The proposal includes a very detailed description of the plans for evaluation, an effort that will be led by a well-qualified consultant with expertise in such processes.

Weaknesses:
- Given the long-term objectives of the Center it would seem that stakeholder involvement (e.g. companies, clinicians, regulators (FDA?)) should play a significant role in helping to prioritize at least some of the R&D efforts. While the proposal does describe its Engineering Innovation Advisory Board and its Community Impact Advisory Board as well as including letters from some anticipated stakeholders, stakeholder engagement does not yet seem strong. A more convincing plan for stakeholder development would enhance the proposal.

In the context of the five review elements, please

evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Engineering Workforce Development:

Strengths
- The science and engineering underlying women's health issues is under-developed and there is an opportunity to cultivate a community researchers, entrepreneurs, and leaders with integrated and inclusive educational programs.
- The proposed center can establish the language and a conceptual framework within which women's health issues can be discussed and addressed with greater ease, clarity, and comfort.
- There is a strong and detailed plan to both make a curricular needs assessment and measure the impact of curricular interventions the team intends to make.

Weaknesses
- The development of curriculum modules on targeted topics related to STEEM and women's health for deployment in a K-12 environment (specifically to 5th grade/middle school) makes an underlying assumption that the teachers involved have the release time to implement these modules and that these new modules will satisfy curriculum requirements met by the existing course material that they replace. While the proposal appears to acknowledge this challenge and outlines a possible NSF RET program to address it, the rigidity of the K-12 curriculum/environment will render a high level of success difficult to achieve. Outlining more specific prior experience with this avenue of outreach and EWD would be helpful.

Diversity and Culture of Inclusion:

Strengths
- The leadership team (Fig. 3) is very diverse.
- Each of the four core universities has some level of ongoing and credible (e.g. NSF ADVANCE) effort to address issues of diversity and inclusion.

Weaknesses
- The self-study program appears more outward looking (what are other universities and institutions doing) rather than inward looking (is IMWEL diverse and inclusive and how can it become moreso).

Innovation Ecosystem:

Strengths
- The proposal highlights that Columbia University has a strong track record on IP and commercialization.
- The proposal includes a draft Membership Agreement plan
- The proposal describes several activities it will pursue to cultivate its Innovation Ecosystem. Among these are: Innovation Fellowships; an annual Design Challenge; and Innovation Summits to be held in conjunction with the Center's annual meeting.

Weaknesses
- The current effort to lay the foundation for an innovation ecosystem seems to be minimal, particularly in the area of stakeholder identification and engagement. It's unclear if the Center will find itself along a path to be self-sustaining after the 10-year NSF funding period.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

ERC Integration:

It's clear that better addressing issues of women's health can have significant societal impact. Furthermore, it seems that the majority of current research in areas of women's health, particularly on the topics addressed by this proposal, is clinically, rather than engineering, oriented. Success of the proposed Center can thus bring a foundational change to how issues of women's health are addressed in the future. In terms of strategic planning, the proposal outlines plans for each of the four foundational elements of a convergent center. Notably, the research strategy includes a detailed timeline that illustrates graphically how various research thrusts and enabling technologies are categorized and expected to develop over time within the three testbeds. The EWD, DCI, and IE each have a set of milestones defined for the initial 10-year funding period. While there is little explicit integration of these strategies, the proposal does include plans for a detailed self-evaluation, part of which addresses specifically the issue of the extent to which the center has successfully integrated the four foundational center elements.

The proposed center will initially involve 33 investigators from four different institutions. This investigator group brings expertise to all aspects of the proposed center activity. The group includes expertise in team science (TSAL = Team Scholarship Acceleration Lab at UC Irvine). It furthermore involves the Magee - Womens Research Institute, which is associated with UPitt and is the largest such research institute focused on women's health in the U.S. The proposal could be strengthened if it more clearly explained the rationale behind choosing these four particular institutions to collaborate on a major center-level activity. It is, for example, not clear to what extent, if any, subsets of the various team members may already be collaborating at various levels and in various ways. The ERC planning grant, described in the Results from Prior NSF Support, makes no explicit mention of such interactions. A thread of existing collaborations and relationships would certainly enhance the success of a center-level activity, particularly in its early stages. Beyond the investigator team, the proposal also describes a set of stakeholders from industries relevant to women's health. It seems that the space of directly relevant companies is relatively small, perhaps because the mechanobiological approach to women's health is relatively new. The proposal could, however, include more explicit description of stakeholder needs, either current or anticipated. While the proposal's discussion of its Innovation Ecosystem mentions needs-driven innovation, one could anticipate some stakeholder engagement and perspective at the proposal stage of such a center-level activity using concepts like those of an I-Corps initiative.

Summary Statement

The proposed ERC IMWEL will introduce a new perspective - mechanobiology - to key areas of women's health in a manner that has not yet been achieved by research at the small-group/individual level. The center will integrate engineering and science expertise in mechanics, cell and molecular biology, and computation/multiscale modeling to address basic problems associated with women's health, primarily related to pregnancy because of the mechanical deformations over multiple length scales that are unique to women. Extreme mechanical deformation of tissues and organs in women is a differentiating feature of the center's focus. Such a center has potential to be very impactful both in terms of enhancing healthcare and patient wellbeing as well as cultivating a new community and a language for this field as it grows. As formulated, the proposal is particularly strong at the knowledge base, and the center seems to be organized preferentially from the bottom up. The proposal could be strengthened with a clearer definition of its engineered system, more specificity with its testbeds, and greater stakeholder engagement, so that a needs-based perspective would organize the center from the top down to define/prioritize the knowledge base.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

IMWELL (Integrated Mechanobiology for Woman's Health) aims to develop engineering systems to overcome specific women's health challenges: preterm birth, pelvic floor disorders, and aging. The compelling new concept undergirding these engineering systems is an interdisciplinary effort to develop multiscale biomechanical computer and imaging, mechano-organs (the use of ex-vivo models to understand mechanical forces on function), clinical deployable devices (new materials, sensor, tools, software), and big data and bioinformatics. IMWELL aims to advance fundamental knowledge in experimental cellular and tissue mechanics, mechanobiology, multiscale theoretical mechanics, and mechanomics (signaling pathways and genomic signatures associated with cell-level mechano-sensing). The proposal should have a profound societal impact by creating an urgently need infrastructure/center for integrated engineering search to advance technologies to prevent and/or treat health challenges that uniquely or disproportionally affect woman, develop a diverse community for education and workforce development, as well as a mechanism for technology translation.

Research:
o The proposal is quite ambitious by integrating multiple length scale experimental and modeling approaches (spanning molecular to organ) coupled with mechanobiology / biomechanics to understand the highly complex health challenges with origins in biomechanics and mechanobiology that uniquely or disproportionally affect woman.
o A strength of this proposal is the interdependency of the research; for example, identification of signaling pathways and genomic signatures on cellular levels is needed to understand the dynamic structural cues for tissue remodeling as well as understanding mechanical forces on cellular and biomolecular responses, all tied together by a big data/modeling effort.
o The proposed research should lead to much needed new discoveries and technologies (new materials, more appropriate tissue models etc.), tools, and data.
o The potential for new diagnostics or therapies represents enormous payoff for the proposed center; particularly for the 3 three testbeds, each affecting a significant patient population.

Infrastructure:
o This proposal has assembled a very strong leadership and technical team with diverse representation and expertise.
o A robust management structure, including advisory boards and committees has been developed to implement and evaluate various center activities.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Engineering Workforce Development:
o In addition to providing a robust engineering workforce development plan that is well-aligned with the overall goals of the proposed ERC, this proposal offers a unique opportunity to have more open, clear, and comfortable conversations about women's health. A particular strength of this proposal is a series of middle school based randomized interventions initially implemented in NY and CA, with plans for expansion.
o Another strength of the EWD is early coordination with DCI initiatives to provide modules for training and/or experiences from middle school to undergraduate students.

Diversity and Culture of Inclusion:
o A strength of this proposal is that several teams have had experiences and received awards for Equity Achievement or implementing inclusive practices for STEM, that can be built upon at this Center. A strong management plan for leveraging past experiences has been articulated.
o The nature of this work is conducive for conversations and engagements on understanding the policies, practices, and procedures that may inadvertently impede STEEM, particularly those focusing on women's health.

Innovation Ecosystem:
o The proposal details a well thought-out plan for an innovation ecosystem that includes understanding and identifying unmet needs, designing/developing/testing, and partnering to validate and deploy new technologies.
o The lead institute has a strong track record of technology transfer and building a network of trusted partners. The innovation ecosystem would benefit from a wide range of stakeholders that include academia, industry, and others.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

The proposed ERC has enormous potential societal impacts by providing new tools and treatments for addressing common woman's health issues. The proposal presented a cohesive and integrated strategic plan to address key elements of each component and provided convincing examples of various interaction. The proposal has assembled a diverse, multidisciplinary, and highly qualified team to ensure a convergent approach. The proposal provides strong commitment from all core partner institutes, a sound strategy for engaging relevant stakeholders, and an excellent framework to guide the implementation of the strategic plan and the evaluation of the Center performance.

Summary Statement

This is an excellent proposal with potential for profound societal impact by creating an urgently need infrastructure/center for integrated engineering search to advance technologies to prevent and/or treat health challenges that uniquely or disproportionally affect woman, develop a diverse community for education and workforce development, as well as a mechanism for technology translation.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Vision: The IMWEL center will use engineering innovations to overcome women's health challenges using a women-centered design approach. They will train the next generation of engineers to contribute to this nascent field. The proposal seeks to bridge the gaps between computational tools and ex vivo systems. The focus is on women-centric physiology to develop models and devices to improve women's health. The proposal integrates biomechanics and mechanobiology, a women-centered approach and engineering innovations to advance women's healthcare. In particular, the center hopes to understand how cells respond to mechanical loads and undergo tissue remodeling and use those insights to build multiscale biomechanical models. The long-term vision is to use the knowledge advances about mechanical forces in understanding diseases that disproportionately affect women.
IMWEL's engineered system will include a system of technologies to restore and support the biomechanical form and function of the female reproductive, cardiac and musculoskeletal physiology. The testbeds represent a health challenge that affects women and is related to biomechanics or mechanobiology. Their goals are to measure, model and make – measure properties of tissues, identify properties they must model, and make devices using improved computer representations.
The proposal takes a women centered approach in understanding, modeling and in design. Additionally, they also plan to develop an integrated education program in female reproductive bioengineering. The center hopes to measure multiscale aspects of genetics, cell biology and tissue biomechanics, construct in silico models in testbeds, and make new devices for research and clinical treatment.
The targeted societal impact is on women's health, which impacts more than half of the world's population. The center's activities and a woman-centered approach to understand mechanical forces in women's physiology and make devices that can improve women's health aligns with the societal impact on women's health.
IMWEL integrates science, technology, engineering, entrepreneurship, and mathematics – a convergence of disciplines that are possible only through a center framework.

Research:
Strengths
o The focus on women's health and the women centered approach is a strong aspect of the proposal.
o The test beds selected provide a range of scenarios, including both health complications and normal, healthy aging.
o The research activities can result in diagnostic and predictive solutions to prevent complications

during birth. In particular, their goal is identify high risk women and develop patient specific interventions is noteworthy. Through their modeling efforts, their goal is to advance knowledge regarding injuries during birth and develop devices thar promote healing.
o The proposed research has direct implications in understanding and potentially preventing pre-term births, which is the leading cause of childhood death.
o In two of three test beds, their focus is on a public health problem that has both safety and financial implications.
o The focus on physical exercise and healthy aging of women as one of the test beds is a strong aspect of this proposal.
o The research is convergent including experts in engineering, medicine and computer science.
o The proposal clearly lays out the payoff from conducting this research in improving women's health during birth and their lifespan, and addressing an important public health problem affecting women and children.
o The proposed research employs a women centered approach to designing technologies and tools to improve women's health – this is a critical need and gap, and it is noteworthy that it is the underlying focus in all of the center's activities.

Weaknesses
o The proposal would have been stronger with a bit more data and specifics on how mechanical forces might complicate women's health in both their specific testbeds as well as the range of diseases the proposal envisions that the center will impact in the future. The evidence for the specific complications that women face without this center could have been described better.
o The evidence for associations between exercise as a testbed and women's health in general, and complications during birth could have been described stronger. While exercise seems to be an important part of maintaining and improving women's health, the evidence or lack thereof to improving women's outcomes could have been articulated better.
o The proposal could have described in more detail what the women centered design approach entails. The proposal lays out a few examples of what is not a women centered design with failed technologies or products. But it is not clear what specific steps or approaches the center's activities will use to follow a women centered design approach.

Infrastructure:
Strengths
o The leadership team is well-qualified.
o The management plan is appropriate for conducting center activities
o Annual meetings outreach events are planned to seek feedback from stakeholders.
Weaknesses - None

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Engineering Workforce Development:
Strengths

o The focus is on creating a language and conceptual framework for talking about women's health
o The proposed center, if successful, will engage trainees at different levels and intervention sites ranging from middle school to teachers.
o The center also sufficiently tailors its activities based on the cohort. The focus on perceptions about women's health and addressing barriers in communicating about women's health is interesting.
o The proposed approach in making trainees aware of women's health issues and making them comfortable to speak about it aligns well with the center's overarching vision in improving women's health.
o The proposed approach is likely to interest and make middle schoolers and undergraduate students more aware of women's health issues and will help recruiting them into this field.
o The plan for engaging partner institutions is appropriate.

Weaknesses
o The RET planned for teachers could have been articulated in more detail. It is not clear what the center plans to achieve by integrating their WIMEN concepts into the curriculum.
o While the proposal articulated plans for engaging middle school students and undergraduates, the plan for training graduate students and post-docs could have been stronger. Graduate student training was focused more on the innovation section, but specific strategies to recruit and train graduate students and post-docs could be articulated better. It is not clear if the strategies identified will lead to substantial impact in workforce development for graduate students without sufficient details.
o The proposal states that the EWD interventions will train a variety of stakeholders including engineers, basic scientists, entrepreneurs etc., but the plans to do so should be described clearly in the proposal.
o The proposal could better articulate how the proposed interventions help in increasing the expertise pool needed to tackle this challenge. If this problem needs a convergent solution, then the approaches in workforce development has to consider convergence as well. Additionally, a stronger focus on training and preparation in the technical fields needed to address these challenges would strengthen the proposal.

Diversity and Culture of Inclusion:
Strengths
o The institutional context for supporting DCI goals is strong with the lead institution being HSI and other institutions continuously working towards improving diversity and inclusion.
o The proposed center will use existing structures such as NSF LSAMP for their recruitment efforts to ensure a diverse community of students.
o IMWEL will conduct a self-study to understand its ecosystem and develop an inclusive culture, which might provide indicators for improvement.
o The proposed center plans to integrate existing knowledge about team science and DCI best practices into their system, ensuring that DCI goals are addressed.
o The focus of this research on women's health, and the disparities in women's health nicely lend itself to study and model DCI goals.
o The management plan provides clear responsibilities for supporting goals – EWD and DCI goals are integrated.
o The proposed center will engage team science experts to provide training to the center member.
o 18 of the 33 IMWEL team members are women.

Weaknesses
o More details regarding the design data collection for DCI would have been useful – what do these different instruments hope to gather? For example, social network analysis is used, but it is not clear how it feeds into the milestone achievement goals for diversity, equity and inclusion.
o One of the proposed millstones is to achieve sufficient diverse leadership by year 5. Details on the strategies to do this should be clearly articulated.
o Specific plans to promote a culture of inclusion would have strengthened the proposal.
o Details regarding diversity and demographics of the current IMWEL team members would have helped understand how future refinements would change this composition.

Innovation Ecosystem:

Strengths
o The center leverages several existing programs to spur innovation efforts and has the potential to succeed.
o Innovations Fellowships will enable participation of graduate, post-doctoral and clinical trainees with emphasis on URM population significantly increasing the potential for workforce development goals. The fellowship program builds on an existing program, so any challenges in training can potentially be identified earlier. The innovation summits are planned to promote networking among various stakeholders and the opportunity to begin new partnerships.
o The plan to leverage existing programs for research translation is strong, in particular with the development of accelerator programs.
o The engineering innovation advisory board is planned to provide innovation oversight and feedback throughout the product development lifecycle.

Weaknesses
o The efforts to engage both IMWEL members and other stakeholders in innovation summits is beneficial; however, plans and mechanisms to engage and encourage the IMWEL core research thrust teams to ideate could have been articulated better. Currently the innovation summit is a yearly challenge, so more routine processes and structures for the team to ideate and move towards implementation would make the proposal stronger.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

The center's activities have the potential to improve women's health, and develop diagnostic tools to prevent injuries and assess risks. Given women's health challenges have significant safety, policy, public health and financial implications, the work conducted in the center has the potential to have an impact on women. The training activities and workforce development efforts could be better integrated with the goals of developing the future workforce to contribute and lead work in this field. The

women-centered approach proposed is interesting and potentially will transform how technologies are designed to promote women's health, but this approach needs to be described in more detail. The foundational component of EWD could be better integrated in the strategic plan. The integration of EWD and DCI are articulated. Evaluation is aligned around implementation assessment, formative and summative evaluation. The evaluation plan is appropriate to assess the center's strategic plans and activities. Sufficient details are provided regarding planned evaluation design and the overarching questions guiding the evaluation. The plans for sharing evaluation feedback are appropriate. Most of the leadership team has expertise in different disciplines within engineering, and includes experts from medicine only as non-lead senior personnel. Given the scope of research activities will center around women's health complications, having experts from medicine in the leadership team might make this team stronger. Similarly, the majority of team members are from engineering, although the expertise they contribute to this project is diverse. The proposed center has significant and strong institutional commitment.

Summary Statement

The IMWEL center will use engineering innovations to overcome women's health challenges using a women-centered design approach. Given women's health challenges have significant safety, policy, public health and financial implications, the work conducted in the center has the potential to have an impact on women. The women-centered approach proposed is interesting and potentially will transform how technologies are designed to promote women's health, but this approach needs to be described in more detail.

Title:NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)
Institution: Columbia University
NSF Program:ERC-Eng Research Centers
Principal Investigator: Guo, X. Edward

Rating: Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Project Summary
This proposal, by a team of researchers from Columbia University, East Carolina University, University of California Irvine and University of Pittsburg, aims to develop an engineering research center (ERC) for integrated mechanobiology for women's health (IMWEL).

Strengths
VISION:
- The team identifies an important and challenging problem to tackle by establishing an ERC to address women's health.

- The team selects an integrated mechanobiology approach as a main anchor for the center's theme and plans to spread the use of mechanobiology and mechanical forces in the lexicon of medical care for women in pregnancy and childbirth.
RESEARCH:
- Convergent research will include measurements and modeling of biomechanical adaptations associated with the human reproduction, postpartum repair, and aging, and device development for clinical diagnosis and intervention purposes.
- Given that the biomechanics and mechanobiology of the human reproduction system are not well understood, the proposed research will certainly shed new insights into the unknowns and introduce mechanical terminologies to the medical care of pregnancy and childbirth.
- Structure wise, the proposed ERC has components including four research thrusts, four enabling technologies, and three testbeds.
-
INFRASTRUCTURE:
- The leadership team is well qualified with technical expertise in biomechanics, computational mechanics, as well as workforce development, and diversity and inclusion.
- The team is well represented by women and minorities faculty.
- Management structure will be guided by a team-science approach supported by an in-house expert. All key components are present, including council of deans, various committees and advisory board, and student participations.
- Annual meetings are planned.
- An evaluation plan is presented with the leader of the center for research in education and societal

policy serving as the evaluator. All aspects of the proposed activities will be evaluated.

Weaknesses
VISION:
- The idea of anchoring this ERC on a mechanobiology based approach to solve the problems associated with difficult pregnancy and childbirth appears to be a bold move and it seems in contrary to what a true convergent research approach should call for.
- It is conceivable that an ERC would be necessary to take on challenges associated with women's health, but the narrow focus on pregnancy and childbirth and its mechanical-based approach could limit the societal impact of the ERC.
RESEARCH:
- While the proposal argues for the need to elevate engineering research in the area of women health, it did not articulate well why using a mechanobiology approach can deliver desired outcomes. In other words, it is not convincing that the difficult pregnancy and childbirth are just a biomechanical problem.
- The proposal mentioned building wearable strain gages and organ on a chip models among other devices but without giving any detail. For example, it is not clear what kind of strain gages will be developed, how will they be applied, to which tissues or organs will they be applied, and if they have the required sensitivity and strain capacity to measure the overly compliant soft tissues. Moreover, in view of the fact that pregnancy and childbirth began since the beginning of human history, without any patient specific information, it is not clear how the in-silico tools can predict a woman's injury potential. Another issue is that exercise will be introduced to animals or humans, and tissue from the cardiovascular system will be collected for analysis; without knowing the intrinsic mechanical environment induced during exercises, how will the collected information be related to the mechanobiology of the reproduction system?
- The aims of research thrusts, enabling technologies, and testbeds seem to be disorganized and redundant at times. The four research thrusts are too heavily focused on biomechanics, lacking the necessary convergent scientific information to tackle the problems. Some sections of the technology areas and testbeds read like basic research components, for example, in testbed 1, devices and tools will be developed, rather than deployed for clinically relevant applications. Most of the tasks in the testbeds will still be done on animals and not on human, posing concerns over its societal impact, as animal studies are supposedly done in one of the research thrusts.

INFRASTRUCTURE:
- In the leadership chart, it is unclear why the two people responsible for diversity and culture of inclusion are placed in the third tier under the center's deputy director. Also, details on operational management seems still sketchy and some are yet to be developed.
- While it is great to have domain expert to lead the program evaluations, the overall evaluation plan seems to focus on people who are part of the ERC activities including advisory boards and external committees. Without feedback from non-participating parties and stakeholders, it risks in getting biased self-congratulatory outcomes.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Strengths
ENGINEERING WORKFORCE DEVELOPMENT (EWD):
- Training of students across multiple stages from middle school, high school, to undergraduates, graduates, post-graduates are discussed with development of course contents and curricula on subjects relevant to women reproductive system.
- Annual meetings, network events and SBIR/STTR training opportunities for graduate students, postdocs are planned.

DIVERSITY & CULTURE OF INCLUSION (DCI):
- The leadership team reflects well the ERC commitments to DCI with people from diverse demographics.
- All participating institutions have a good track record in promoting DCI.
- The ERC will plan social events to continue promote and enhance DCI among faculty and student participants.
INNOVATION ECOSYSTEM (IE):
- The ERC will launch an innovation fellowship to equip aspiring innovators with the right experience and skills in women-centered medical field by taking advantage of an existing program.
- The ERC will launch a design challenge for women's health to feature technologies from the IMWEL.
Weaknesses
ENGINEERING WORKFORCE DEVELOPMENT (EWD):
- It is not clear how practical it will be to teach courses on women reproductive system to middle/high school students and engineering undergraduates.
- EWD activities seems to narrowly focus on student training and K-12 outreach. Not much discussion is given on graduate student and trainee recruitment and retention, and no mention of industry partnership and professional school participations.
DIVERSITY & CULTURE OF INCLUSION (DCI):
- There is not much discussion on efforts to recruit and retain faculty and trainees from diverse demographics, as well as glooming some of these participants for leadership skills. The listed DCI achievements lack some clear metrics, raising convers over evaluation of successes in the area of DCI.
INNOVATION ECOSYSTEM (IE):
- None noted.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Strengths
- The proposal presents an interesting idea and bold approach to address women's health challenges in the reproductive system.
- Support from all participating universities seems strong with all engineering deans expressing commitments to provide necessary resources and personnel.
Weaknesses
- Due to its heavy reliance on a biomechanical based approach, the potential for providing practical solution to women's health in the reproductive system seems doubtful, hence its high societal impact

could be limited.

- The expertise of the leadership team seems centered in narrow areas of mechanics, biomechanics, mechanobiology areas and computational mechanics, contrary to what a convergent scientific approach should look like.

Summary Statement

The proposal identifies an important problem in women health as the central focus for this ERC. The team is well represented by diverse demographics and the management plan is sound. However, its narrow emphasis on pregnancy and childbirth and its simply reliance on a biomechanical approach to address such a complex problem may pose serious challenges for the team to achieve the expected outcomes.

INSTITUTION:	Columbia University
NSF PROGRAM:	ERC-Eng Research Centers
PROPOSAL TITLE:	NSF Engineering Research Center for Integrative Mechanobiology for WomEn's HeaLth (IMWEL)

PANEL SUMMARY:
Panel Summary

Project Summary:

IMWELL (Integrated Mechanobiology for Woman's Health) aims to use mechanobiology and biomechanical approaches to overcome specific health challenges (preterm birth, pelvic floor disorders, and healthy aging) that disproportionately affect women.

Intellectual Merit

Vision:

IMWELL center proposes to use knowledge advances in biomechanics and mechanobiology to bridge the gaps between computational tools and ex vivo models to address health challenges that disproportionately affect women. The center proposes to investigate how cells respond to mechanical loads and undergo tissue remodeling, and use those insights to build multiscale biomechanical models. The center will use four research and technology enabling thrusts with three test beds in preterm birth, pelvic floor disorders, and healthy aging of cardiac and musculoskeletal systems.

Research: There are several strengths and weaknesses in regards to research.

The panel identified the following strengths:

1. The panelists agreed that the focus of the proposed center on women's health is a strength and is an important need; some panelists expressed enthusiasm for the high societal impact that the proposed work could result in.

2. The center will likely make fundamental knowledge advances on how mechanical forces can impact women's health, and how mechanobiology approaches could be used to understand cellular level data. Some panelists felt that this potential to make knowledge advances on the fundamental sciences on women's health makes it a high risk high pay-off work.

3. The vision for the center is quite ambitious in proposing multiscale modeling approaches; the proposed modeling approaches are highly complex, and span multiple length- and size-scales from molecular to cellular and tissue levels.

4. The unique focus on mechanical deformation of the female body during pregnancy, childbirth,

postpartum repair and aging has the breadth and significance to warrant a center.

5. The proposed efforts were interdependent and nicely integrated big data modeling with genomic, clinical, and mechanistic data.

6. Some panelists thought that the focus on mechanobiology is innovative and important because it is not currently well-understood and can shed some new insights on women's health issues.

The panel identified the following weaknesses:

1. Some panelists felt that the vision of the proposed center was unclear making it difficult to assess whether the outcomes were sufficiently measurable; the engineered system needs to be more clearly articulated – some panelists were unclear what the system of technologies meant.

2. There is not enough convergence across the vision, research thrusts and the test beds. Inclusion of a physician scientist in the leadership team would be beneficial given the focus on women's health issues.

3. The proposal mentions a women centered design approach but does not go into details on what this approach really entails and how the proposed efforts will integrate this approach into their efforts.

4. Panelists felt that the scope of the proposed center is narrowly focused on health issues in reproductive system potentially limiting the impact of the work to a broader set of women's health challenges. For instance, other women's health issues such as cancer, osteoporosis might demand the same attention, but because of the focus on mechanobiology, the scope of application and impact on women's health issues appears limited.

5. A related concern was that the narrow focus also limited the impact of the work to patient specific population. The narrow scope on reproductive issues and the explicit focus on mechanobiology also made panelists question the need for a center to address these questions.

6. Lack of experimental details in the proposal does not justify the high risk/high reward components of this center; the limited scope of the center also narrows down the center's efforts from addressing broader questions about women's health.

7. Some panelists also questioned whether the focus on mechanobiology is sufficient to address the women's health issues proposed in this effort. The proposal did not have much detail to convince the panelists for the justification of using mechanobiology approaches.

8. The panelists thought that the center could expand its scope by focusing on Black (and other minority) women's health issues, and the disparities in delivering care, which have a more urgent need. The proposed efforts lack any focus on information about demographics and genetics information limiting the scalability of this work to a larger population.

9. The enabling technologies proposed were not clearly articulated in the proposal – there was not enough justification for using strain gages and organ-on-a-chip models. Details on the organ-on-a-chip

was lacking. Additionally, the panelists felt that there were other non-invasive technologies, and the proposal does not provide enough justification for developing the enabling technologies proposed. The enabling technology, research thrusts and different test beds were not tightly connected making the convergence of the proposed efforts unclear.

10. While the panelists felt that there was potential for clinically deployable devices to have high societal impact, they questioned the feasibility of transforming and scaling these technologies. In particular, there was no clear roadmap on how the knowledge advances will be transformed into technologies.

11. The proposal states that the center will develop predictive models that provide causation data on preterm birth. However, the panelists noted that the approach proposed for these predictive models could only uncover associations and not causation, significantly limiting the benefits from this approach.

Infrastructure

Strengths

1. The leadership team is well-qualified.

2. The team has complementary expertise that will help address the fundamental challenges this center proposes to address.

3. The inclusion of a community impact advisory board is a strength.

Weaknesses

1. The community impact advisory board currently lacks any integration with black and minority women groups and providers. The panel thinks that the advisory board could integrate broader research thrusts on minority women's health issues and engage the corresponding women stakeholders including healthcare providers who play an important role in delivering healthcare using the proposed technologies.

Data Management Plan: The data management plan is adequate.

Broader Impacts

Engineering Workforce Development:

Strengths

1. The consensus of the panel was that this ERC has the potential for high societal impact.

2. The panel highlighted the educational plan as a strength and commended the plan to encourage open, clear conversations about women's health throughout all levels.

3. The panel thought that the planned school based interventions that will be adapted for each community

was particularly strong.

4. The ERC will leverage existing successful programs for recruiting and retaining students.

Weaknesses

No EWD plan weaknesses were noted by the panel.

Diversity and Culture of Inclusion:

Strengths

1. The panel noted the demonstrated commitment of the ERC team and the member institutions to encouraging women and students from underrepresented groups to pursue careers in STEM as a strength of the proposal.

2. The ERC will leverage existing successful programs for recruiting and retaining female and underrepresented students.

Weaknesses

1. Given the fact that the health of women from underrepresented groups is often disproportionately impacted by systemic issues and inequities, the panel felt that the proposal might be strengthened by including considerations of these disparities and prioritizing the dissemination of results and products developed from the research to communities most impacted.

Innovation Ecosystem:

Strengths

1. The panel agreed that the innovation ecosystem plan was strong, and that the lead institution has a good record of innovation and technology transfer.

Weaknesses

1. The panel felt that the innovation ecosystem might be strengthened by the inclusion of constituents from communities most impacted by women's health care disparities on the Community Impact Advisory Board.

Postdoctoral Mentoring Plan:

The postdoctoral mentoring plan is adequate.

ERC Integration

The panel was uniformly excited about the research topic and felt the mechanobiology-engineering approach was compelling. Women's health, and specifically reproductive health is an under-studied area and advancing understanding in this area has the potential for being a foundation for products and insights that have a high impact on women's health and, therefore, society more broadly. However, the roadmap from the models to new products, or how the researchers will distinguish between causation and association was unclear. Therefore, the panel could not be confident and specific about the anticipated impact of the IMWELL proposal. The proposal can also be further strengthened by more description of the integration between the three testbeds. The panel was positive about the integration of cellular, tissue, organ and mechanobiology systems and use of a big data modelling approach. However, the focus on the female reproductive and cardiac systems does not fully encompass women's health and diseases disproportionally impacting women. The research team, evaluation team, and institutional support were appropriate and the panel did not express any major concern, although there was a question raised about the high proportion of funding designated for Columbia University relative to the other partner institutions. The stakeholder engagement plan was appropriate, although the proposal could be further improved with inclusion of stakeholders specifically focused on improving Black women's maternal health.

The panel summary was read by/to the panel and the panel concurred that the summary accurately reflects the panel discussion.