



Ten-Page Response to Full Proposal Reviews

STC: Learning the Earth with Artificial Intelligence and Physics (LEAP)

We appreciate the review panel's supportive comments, including that "[LEAP] connects to six of [the] NSF's Big Ideas, [and] will impact research and society," that the "project is exceptionally well suited for an STC," and that the "team is in many ways the best qualified in the world." We exclusively focus this report on areas in which reviewers request improvements, with verbatim review comments as headers followed by our responses. Key components of our response fall under seven high-level categories:

- Describe our cultural values, transparent management structure, and the explicit reflective practices that will allow us to achieve LEAP's Convergence Goals (Section 1);
- Plan to support LEAP leadership with coaching and mentorship (Section 1);
- Create a new research engineering position, hired by Columbia and stationed at NCAR, to supervise and support code integration within the CESM (Section 2); and,
- Provide more detail with respect to data management (Section 3);
- Offer additional clarifications on undergraduate and graduate education activities (Section 4);
- Illustrate how our broader impacts activities will have impact and be linked to research (Section 5);
- Clarify and adjust interactions with the private sector (Sections 6 and 7); and
- Increase Geoscience Director Zanna's effort to 1.5 months (Section 7).

In many cases, we could address comments by clarifying or amplifying the original proposal. In some cases, comments have prompted changes in center scope. Sensitive to length requirements, we only highlight the broadest reviewer's comment when several reviewers had similar questions. We are excited to continue refining LEAP in response to this and future feedback.



1. MANAGEMENT, LEADERSHIP, AND CENTER CULTURE

Panel Summary: *"This is a large and complex project that needs to be managed well to be exceptionally successful."* **Reviewer 1:** *"The big challenge will be to promote a center culture among 48 researchers spread across more than a dozen institutions."* LEAP is a large and convergent effort. Success requires creating a culture that supports and integrates our multifaceted goals of research, education, broadening participation, and knowledge transfer. Our research areas are rapidly evolving, requiring flexibility in terms of research focus and funding to optimize center goals. At the same time, we must allocate limited resources fairly. Across all efforts, LEAP must increase the participation of diverse groups (Section 5). To address these challenges, we will structure LEAP around our cultural values, develop processes for transparent decision-making, ensure adequate administrative and advisory support, and regularly reflect on our progress and make needed course corrections.

Center Culture: LEAP will mold center culture around six tenets: 1) developing the scientific basis for improved climate change projections and decision-making; 2) convergent science; 3) open-source science; 4) integration and translation of research across broadening participation, education, and knowledge transfer initiatives; 5) proactive steps for diversity, equity, and inclusion (DEI) in all activities; and 6) transparent leadership and operations. These tenets will be molded into a statement of Center Values that will feature prominently in LEAP's Strategic Plan and Ethics Handbook. As described below, our management structure and the organization of research projects will foster this intended culture. At our annual meeting, we will reserve time for all LEAP participants to reflect on the success of or issues in our implementation of this culture, and strategic adjustments will be made as needed.

Management Structure: The Executive Committee, Convergence Subcommittee, Knowledge Transfer Subcommittee, and Climate Justice Leadership Board each have specific and complementary responsibilities. Two advisory boards will help assess progress and support center management: An External Advisory Board and a Director's Council. A full-time Managing Director, supported by four additional full-time administrators, will ensure that research, educational, broadening participation, and knowledge transfer initiatives

have proper operational support. LEAP will recruit, mentor, and retain diverse administrators who contribute to and benefit from our convergent culture (Section 5).

Project Funding: Distribution of project funding is a critical managerial task. For Columbia-based projects, researchers will annually propose projects through a two-page description of: 1) research objectives, plans of work, and maturity level (see next sub-section); 2) the expected path forward to Earth System Model (ESM) implementation; and, 3) planned contributions to integrated broader impacts. The Convergence Subcommittee (Proposal F6) will be responsible for funding distribution, and will select a portfolio of projects balancing maturity level, model parameterization versus data product or metric development, data-knowledge spectrum (Figure 5 in proposal) and areas of science (e.g., land, ocean, atmosphere, cryosphere, or the coupled model). LEAP will distribute funding in two- to three-year increments for postdocs, and one-year increments for Senior Personnel and graduate students, with an option for progress-based renewal. A mid-year progress report will enable the Convergence Subcommittee to track progress. In addition to this primary funding mechanism, LEAP will distribute seed funding to support high-risk/ high-reward ideas (Proposal B9).

Structuring Research: LEAP’s multi-layered structure encourages convergence across research, education, broadening participation, and knowledge transfer initiatives, with multiple pathways for sharing skills and techniques. To clearly structure research efforts to meet overarching center goals, LEAP categorizes research projects into three maturity levels (Figure 1):

- **Level 1:** Proof of concept/ exploratory science;
- **Level 2:** Implementation in an uncoupled model, or data product development; and
- **Level 3:** ESM implementation of new parameterization, or development of a new data-based metric for ESM assessment.

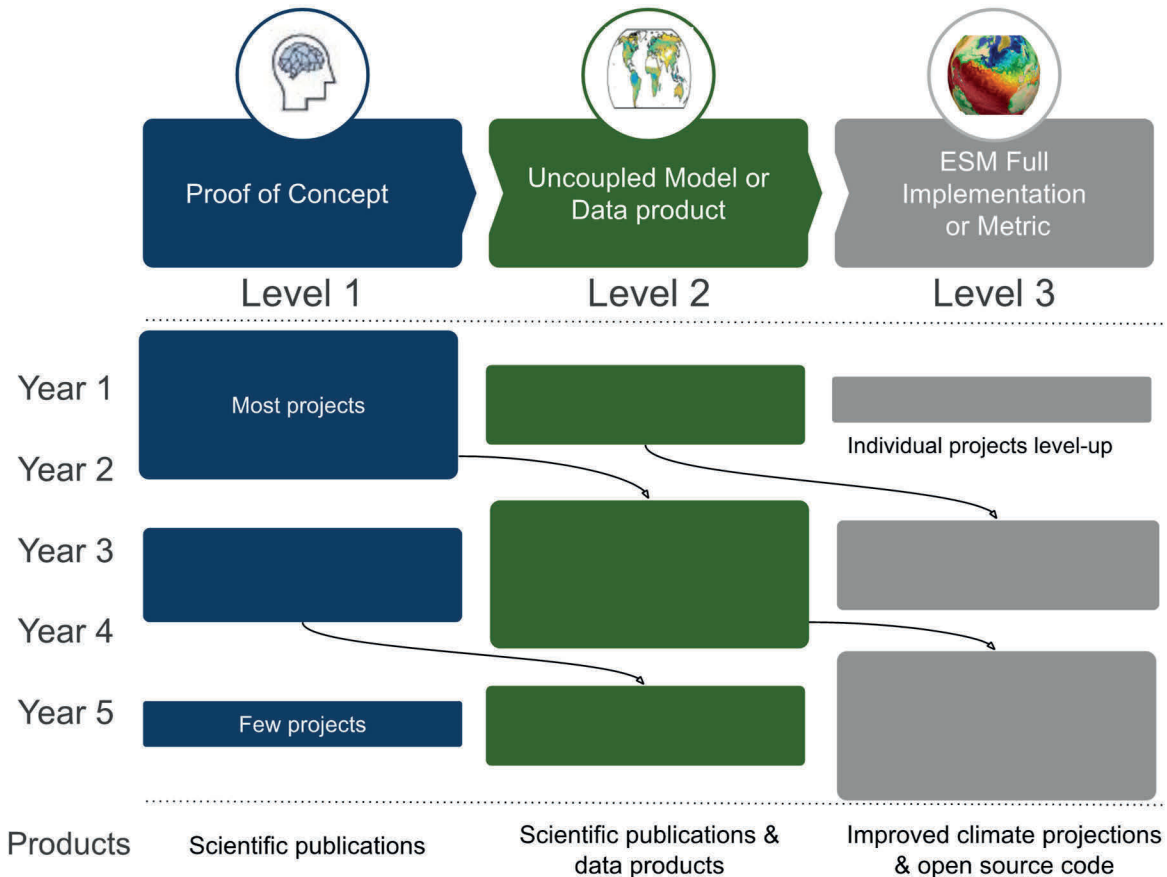


Figure 1: LEAP project levels, and schematized timeline of relative balance in the overall research portfolio.

Year 1 will include mostly Level 1 projects¹; by Year 5, most projects will have transitioned to Level 3. Level 1 and 2 projects will have to describe how and on what timeline they will reach Level 3. The Convergence

Subcommittee will award funding based upon the merits and recent progress of each individual project, and also on the desired balance of Level 1, 2, and 3 in LEAP's overall research portfolio throughout the years. Tracking projects across years will allow leadership to assess overall progress toward Convergence Goals, and support adjustments. LEAP will use project management software, such as Teamwork, to streamline project progress tracking. LEAP will contribute to the ongoing promotion of alternative metrics in academia, including open-source data and software [1] by targeting different metrics of success for each level. Success will be assessed based on publications at Level 1, while for Level 2 it will be based on either publications or data products. Level 3 success will be based on ESM integrations with published code and publicly available model output (Figure 1).

Research Collaboration & Working Groups: LEAP's research projects have overlapping interests and needs (Proposal B4, B5, and B6). To further foster integration, all LEAP researchers will participate in research working groups. Geoscience Director Zanna and Data Science Director Vondrick will determine appropriate groupings each year, which will evolve based on participation and relevance to existing science. Working groups will meet biweekly in person and on Zoom, and use Slack for more frequent interactions. Working groups will foster center culture in terms of convergent and open-source science by encouraging frequent sharing of ideas, data, and code.

In addition, convergence luncheons, annual meetings, and the monthly newsletter, described in the proposal, will offer avenues for all participants to learn from others and build new collaborations. Though LEAP does include multiple institutions, many Senior Personnel have already effectively collaborated in the past (e.g. Pritchard and Gentine) using the tools and approaches central to LEAP. This includes common collaboration tools (Slack, GitHub), online seminars and meetings, and shared data and computational platforms (Data Management Plan). The current pandemic has further confirmed that computationally-oriented research could be efficiently performed at a distance.

Operational Manual: LEAP will develop an Operation Manual detailing key activities and procedures, so that all LEAP participants understand the underlying basis for leadership decisions. Example sections include: 1) distribution of funding; 2) authorship policies; 3) research working groups and responsibilities; 4) hiring; and 5) conflict resolution. In the first three months of STC funding, LEAP's Executive Committee will author the document, soliciting input from the leadership coach and the LEAP community. In addition to being a mechanism for transparency, this manual will empower LEAP's leadership to make decisions that are within their areas of responsibility, which will streamline operations. Issues not adequately addressed by the manual will be discussed at monthly Executive Committee meetings. The manual will be open-access and updated annually.

Annual Meetings: Within three months of the award, LEAP will hold a two day-long Kick-Off Meeting with all LEAP personnel (senior personnel, students, postdocs, administrators) to develop the shared vision and center culture. We will discuss drafts of the Strategic Plan, Ethics Handbook, and Operations Manual. In subsequent years, the proposal planned an annual three-day DEI Workshop. To respond to Reviewer 1's question about our promotion of center culture, we will modify this Annual Retreat: Day 1 will promote a culture of collaboration through review of research, education, and knowledge transfer outcomes. On Day 2, participants will engage in the proposal's conceptualized DEI workshop. On Day 3, we will reflect on operations and progress, so that we can make adjustments to the Strategic Plan and Operations Manual.

Broadening Participation: The geosciences severely lack racial and ethnic diversity: Still today, only ~5% of PhDs self-identify as people of color [2]). This is not acceptable, and requires a sustained effort to which LEAP is committed. One of the six tenets of center culture is "*proactive steps for diversity, equity, and inclusion (DEI) in all activities.*" We have deliberately decided to provide the needed resources for implementation of established best practices in recruitment and training, rather than to focus upon innovation (Section 5). LEAP's leadership and administrative team will have training in inclusive management practices. Per several reviewers, our leadership team is exceptionally innovative, with Chief Equity Officer Cogburn authoring high-impact articles that relate to diversity research (e.g. [3]). Supported by LEAP's iterative strategic planning process, we will continue to evaluate opportunities for DEI innovations.

Panel Summary: *"The PIs appear not to have significant experience in managing large center-like projects, and this could present problems in fully promoting the center culture and coordinating all the moving parts."* While LEAP's leadership has held a variety of professional leadership positions, we

concur with the panel that an STC management can be a unique challenge, one which we take very seriously. To address this, we commit the following new steps to rapidly advance our management skills.

- **LEAP Management Institute.** Supported by the cost share, in Year 1 we will create a new “LEAP Management Institute.” This formal training program will consist of 15 hours of classes, spanning Understanding Style and Differences, Leading and Managing, Team Roles and Project Groups, Problem Solving, Conflict Negotiation, Measuring Organizational Performance, and Inclusive Management. In Year 1, LEAP’s leadership team will be trained by the Institute. In Years 2-5, ten participants will enroll per year, including faculty, postdocs, graduate students, and administrators.
- **Executive Coaching.** Dr. Paul Ingram, Kravis Professor of Management at Columbia’s Graduate School of Business, will be added as a paid consultant and serve as Center Director Gentine’s and Deputy Director McKinley’s Executive Coach, supported by institutional cost share. This coaching program will include: 1) formal monthly, hour-long sessions; 2) ad hoc coaching conversations; and 3) general organizational development. Ingram will support establishing, refining, and evaluating key Center priorities, and translate high-level goals into measurable actions. Ingram will regularly solicit anonymous feedback from LEAP’s team on Gentine’s and McKinley’s effectiveness and progress.
- **Mentorship Program.** Columbia successfully operates multiple extramurally-funded STEM research centers, including an NSF Materials Research Science and Engineering Center and a DOE Energy Frontier Research Center. To leverage this experience, Columbia’s Engineering Dean will launch a “Center Director Mentorship Program.” Gentine will join other Center Directors in monthly hour-long meetings to resolve institutional barriers and share best practices in research administration, strategic planning, human resources, and facilities management.



2. RESEARCH

Reviewer 2: “The modeling centers’ role could be more substantive.” Fully implementing and testing new code into NCAR’s CESM requires: 1) ensuring code quality and monitoring its integration within the modeling system; and 2) domain expertise. These often require proficiency beyond postdoc and student capabilities. To achieve success: 1) NCAR will co-sponsor NCAR Senior Personnel time to mentor visiting postdocs and students, review code, and supervise code integration into the CESM; 2) Students and postdocs from Columbia, NYU, Irvine, and Minnesota will visit NCAR for full semesters and/ or summers (carbon-offset travel and housing are already budgeted); and 3) LEAP will hire one new Research Scientist, employed by Columbia (supported by the institutional cost share), but physically based at NCAR. This person will co-supervise project development and CESM implementation, in close collaboration with LEAP’s other already-budgeted research scientists (Wang, Elsaesser, van Lier-Walqui, and Porter). NCAR’s Senior Personnel have extensive experience collaborating with universities to develop CESM2 and prior versions. CESM has a governance structure with Working Groups composed of representatives from NCAR and the broader research community. LEAP researchers will join relevant CESM Working Groups to participate in model development decision-making processes and communications. Any features or parameterizations not immediately adopted into the default model version will become an option for scientific exploration and assessment by the broader community.

NASA GISS is an integral LEAP partner. LEAP will collaborate with GISS to define new remote-sensing based metrics for model evaluation. As with NCAR, this includes defining new metrics and diagnostics utilizing NASA satellite retrievals via Machine Learning (ML) algorithms. Finally, GISS will test and implement LEAP’s ocean and atmosphere ML parameterizations in ModelE, as supervised by their software engineering team. Several Senior Personnel from GISS (Schmidt, Weng, van Lier-Walqui, and Elsaesser) will facilitate this collaboration.

Reviewer 2: “I would have liked to see a statement of what specific classes of simulations at NCAR and GISS would be run with the new ML-inspired components, to differentiate it from the previous generation of models.” LEAP will primarily target fully-coupled historical and standard Coupled Model Intercomparison Project (CMIP) simulations. Specific metrics are described below. During the development process, LEAP will assess component simulations (e.g., land-only simulations) before relying upon coupled simulations.

The proposal defines five convergence strategies, including: 1) a systematic, shared data pipeline for climate research; 2) novel or improved subgrid parameterizations for Earth system components based on ML; and 3) new metrics for model evaluation. Though some recent Earth system model work uses ML, LEAP is innovative in endeavoring to improve community ESM for long-term projections using ML and novel data infrastructure. Our open code will rapidly translate improved approaches to other Earth system models, thus benefiting future CMIP and other multi-model research activities.

Further, LEAP will develop parameterizations of all active Earth system components (e.g., ocean, atmosphere, land, and cryosphere), rather than a subset (e.g., Clima or Vulcan both focus primarily on the atmosphere and ocean). LEAP's strategy targets model uncertainty in both model structure and parameters, therefore extending beyond Clima's approach of primarily using ML for systematic parameter tuning in standard (i.e. non ML-based) parameterizations. Vulcan's effort focuses on short-term (year) climate predictions, and not long-term (100-year) climate projections. Finally, LEAP will develop an open-access data infrastructure to benefit the broader community, and translate this knowledge into its education, broadening participation, and knowledge transfer initiatives. Thus, LEAP aims to more directly influence a broad range of stakeholders than Clima or Vulcan do currently.

Reviewer 2: “It is also not completely clear what the ‘cost function’ being optimized is: many aspects and ESM deficiencies are mentioned, including model biases, extremes, etc. Some of these may require trading off one against the other.” LEAP will target Diagnostic, Evaluation, and Characterization of Klima (DECK) simulations (Atmospheric Model Intercomparison Project – AMIP, pre-industrial control, abrupt 4xCO₂, and 1%/year CO₂ increase simulations) and historical simulations, which constitute the basis for comparisons against observations, in addition to documenting the behavior of the model such as its climate sensitivity. When implementing ML-parameterizations, we will initially base the metrics for assessing model improvement upon CESM diagnostic packages, as detailed in the proposal, and include typical metrics for mean biases and variability (e.g., El Niño). Further, CESM2 [4] is being evaluated in multiple ways through its participation in CMIP and numerous complementary Model Intercomparison Projects (MIPs). This allows for an assessment of the model's main biases and shortcomings, providing a basis for CESM3 development, which LEAP will use to identify model improvements.

Beyond existing metrics, LEAP will target additional metrics identified by multiple stakeholder and partner groups. Existing diagnostics packages are often incomplete due to improper diagnostics for higher order statistics (e.g., extremes) and combinations (compound events) most impactful for policy, and which have a disproportionate impact. LEAP will refine these diagnostics based on: 1) recent literature on extremes and compound (i.e. combined) events that generate the most risk [5]; and 2) most impactful diagnostics based on LEAP's bidirectional knowledge transfer initiatives (e.g., identifying the most impactful variables or combinations, and understanding how they can be used as model diagnostics for improved performance). LEAP will then define new metrics via ML. Many fast processes (e.g., low clouds) exhibit biases evident after only a few simulation days [6,7]. LEAP will use these biases with high-frequency sampling to create new ML-based diagnostics targeting fast processes (Proposal B6.3).

Reviewer 2: “While there is mention that NCAR’s computational platform may be available for this project (p8), the computational requirement may be quite high (100M CPU-h may be the order of magnitude).” LEAP will request computational resources from the NSF NCAR-Wyoming Supercomputing Center (NWSC) via the Large University Allocation Request procedure. Several STCs have been granted large allocations on NWSC or prior NCAR computing platforms. 20M core hours per year is indeed significant, but in accord with other large university requests (PI Gentine has already received 10M+ core hours per year for direct numerical and large eddy simulations). In 2022, NWSC will update to NWSC-3, triggering a 300% increase in computing power that will accommodate unexpected increases in LEAP's computational requirements. Importantly, LEAP's participation on CESM Working Groups will procure additional computation resources via the CESM allocation. Further, GISS will support some of the simulations highlighted above and in the proposal based on their existing allocation for model development. If necessary, LEAP will apply for further computing allocation at GISS. Once simulations conclude, we will transfer data to Google Cloud for cloud-based analysis using LEAPangeo.

Panel Summary: “Lamont is huge and this center is a fit for this project. However, reviewers questioned why this work on how data science relates to climate science is not already being pursued.” The review panel correctly highlights the eminence of Columbia's Lamont-Doherty Earth Observatory,

which is a world leader in geoscience. However, LEAP targets a unique intersection that lies at the frontiers of both data science and geoscience. This transdisciplinary participation of scientific communities with experience, training, and capabilities are not currently found at Lamont alone. Instead, this requires unique collaboration across research fields and educational programs. The STC funding mechanism allows for the integration of disciplines across institutions and schools, which is required to achieve LEAP's scientific goals.

Reviewer 7: “I’m not sure how this will be addressed in the project, but the potential for stochastic parameterization should be considered.” Due to space constraints we chose not to elaborate on this in the full proposal (this was alluded to in the pre-proposal, though). Indeed, when and where appropriate, LEAP will test stochastic parameterizations in addition to their deterministic counterparts, because they can affect the mean and variance of climate-relevant variables. We have already made recent progress on this for: 1) precipitation and transport associated with atmospheric convection using conditional Variational Auto Encoder (VAE) (current research by Wang, Pritchard, and Gentine), or Generative Adversarial Network (GANs) [8]; 2) convolutional neural networks with mean-variance loss (current research by Guillaumin and Zanna); and 3) GANs as tests for stochastic subgrid parameterizations in idealized chaotic systems [9].



3. DATA MANAGEMENT WITH LEAPangeo

Reviewer 3: “There isn’t a clear plan for open access to data products, although they do encourage release of code, perhaps with publications. I see no one designated for data management which means a free-for-all approach.” Data & Computation Director Abernathey was designated for data management, and we are delighted that most reviewers were impressed by LEAP's Data Management Plan and LEAPangeo. LEAP will distribute curricula and personnel, engagement, and assessment data via Columbia's Academic Commons. We will distribute scientific data and software via Pangeo's pioneering cloud-based approach. These scientific datasets will be several petabytes in size, thus requiring innovative data management practices. With LEAPangeo, data for training ML models (e.g., satellite data and existing high-resolution simulations) will be compiled into analysis-ready, cloud-optimized formats (e.g., Zarr), stored and cataloged in Google Cloud Storage. Our two Data Engineers will maintain the scientific data catalog. With cloud computing, the same data used internally will be instantaneously shared publicly and broadly. Once STC funding concludes, LEAP will collaborate with Google and Microsoft to keep most datasets into their public datasets. We will deposit data products that cannot be archived on the cloud into NCAR's Research Data Archive. Sharing of code, including ML models, will follow similar cloud-native best practices. GitHub will be the primary repository for code in active development. Upon publication/ release, we will deposit code in Zenodo to generate DOIs (used for Level 1 to 3 product assessment). All published code will be packaged with environment specifications and accompanying Binder configuration (a reproducible, shareable, and interactive computing environment), enabling anyone to launch the code in a cloud-based container and replicate results.

Constrained by space, our proposal did not provide sufficient technical details on LEAPangeo implementation. Our Shared Experimental Facilities Plan surveys all infrastructural elements: the Data Catalog, JupyterHub, Binder, and Dask. LEAPangeo will be part of the broader Pangeo project, an international collaboration involving NCAR, NASA, and multiple other institutions. Rather than specifying all details of a complex infrastructure system, Pangeo practices Agile Development, a software development model involving constant user feedback, adaptive planning, rapid delivery, and continual improvement. Agile will be employed and described in LEAP's Operation Manual. The rapid uptake of Pangeo-style tooling by international organizations [10] highlights its effectiveness at delivering useful cloud-based infrastructure.

Reviewer 7: “One thought that the PIs should consider is developing a crash course in using GitHub and LEAPangeo for incoming Fellows.” This is an excellent idea. We will develop a training course in collaboration with NCAR's NSF-funded EarthCube, entitled “*Project Pythia: A Community Learning Resource for Geoscientists*.” We will use NCAR's platform to share tutorials and best practices, examples of which include: 1) use of version control and Git for scientific collaboration; 2) processing big data in the cloud using Pangeo; and 3) an introduction to ML applications to geoscience. In addition to online self-

paced learning, we will conduct semiannual “boot camp” training workshops for LEAP participants, conducted in partnership with Columbia’s Foundations for Research Computing initiative, which has extensive experience developing and running similar computational boot camps.



4. EDUCATION

Reviewer 5: *“REU planned but no indication of number of new funded positions.”* We budgeted \$50k direct costs per year for a summer-based REU program to support **four faculty-student pairs** each summer, including eight weeks of housing and stipends. Supporting LEAP’s convergence, we will explore as many entry points and recruitment pipelines as possible, spanning coursework, LEAPangeo’s boot camp training, and SOARS. The REU’s requirement of a faculty-student pairing ensures constant mentoring. LEAP will apply best practices for broadening participation (Section 5) at each stage of our education pipeline to ensure a balanced and diverse REU annual cohort.

Panel Summary: *“Aspects of the... mentoring plan are not well laid-out and need to be strengthened.”* LEAP’s convergence provides ample opportunities for faculty to collectively guide all trainee levels, including proposed Management Institute, Convergence Luncheons, the Design Studio, and translate-athons; in concert, these programs develop valuable scholarly skills, supported by a network of researchers and administrator experts (particularly the Staff Writer and Storytellers in Residence). For REU participants specifically, Columbia’s Summer@SEAS program offers research skill workshops and networking events, which provide more mentoring and peer-learning opportunities.

Reviewer 4: *“One other worry for me is where the group will find 40 graduate students... ready to work on this project. 40 graduate students, seemingly all in the same recruitment year.”* LEAP budgeted for 48 one-year graduate fellowships *total* across the five-year award, averaging approximately **ten students per year**; Reviewer 4 might have misread cohort size, and we agree that 48-person cohorts would not be manageable. LEAP will not train 48 different students, because fellowships are renewable for subsequent years based upon project progress and programmatic needs identified by the Convergence Subcommittee (Section 1). Graduate students across disciplines will participate in LEAP research at different stages of their research training, and with different levels of engagement. For example, a computer science student working on theoretical ML may spend one year implementing weakly supervised learning algorithms into cloud microphysics models. Alternatively, a geoscience student interested in ML may be more deeply engaged in LEAP’s research projects throughout her entire PhD duration, and will apply for renewal throughout the course of her PhD by LEAP’s fellowship (based on satisfactory progress). Averaging ten graduate fellows per year is manageable and within LEAP’s scope. We anticipate that fellowship demand will be high, as Columbia’s Data Science Institute trains 350 graduate students per year, and Columbia’s Department of Earth and Environmental Sciences contains 100 PhD students at any time. Importantly, in early July, Columbia’s Board of Trustees voted unanimously to approve a new Columbia Climate School (which we will elaborate upon in the Site Visit). This major and recent commitment will undoubtedly generate strong publicity for LEAP’s fellowships.



5. BROADENING PARTICIPATION

Reviewer 6: *“The diversity recruitment plan is not innovative - weakest part of proposal.”* Geoscience and data science each have somber diversity records. Led by Chief Convergence Officer and Education Director Zheng and Chief Equity Officer and Knowledge Transfer Director Cogburn, we deliberately chose a robust suite of best practices that have been shown to work for other disciplines, rather than invent another approach. Our intentional objective was to achieve results, not to innovate. The STC program’s five- to ten-year lifespan provides a unique opportunity to model the culture we would like to see permeate these two disciplinary fields. It is important to emphasize that Cogburn, who takes a transdisciplinary approach to the study of racism, serves dual roles for LEAP’s broadening participation and knowledge transfer initiatives, further ensuring integration of center activities, and that communication and outreach will be a vehicle for achieving equity and inclusion. In addition, Center Director Gentine is also LEAP’s Diversity Co-Director, intended to ensure that diversity is rooted in all aspects of LEAP’s operations.

Panel Summary: “Reviewers commented that the outreach and science seemed decoupled, and this aspect should be strengthened.” LEAP’s Broader Impact (BI) programming is tightly integrated with research. In the proposal, Figure 6 illustrates shared leadership between research and outreach activities, with LEAP’s faculty directly involved in BI activities. Specifically, translate-a-thons and the teacher professional development program will be informed by LEAP’s research processes and products. Hackathons and journalism workshops will furnish stakeholder engagement with research products (i.e., data sets and research results), and establish mechanisms for constant feedback and operational refinement. Figure 6’s arrows document pipelines and connections between LEAP’s research, education, broadening participation, and knowledge transfer efforts. Quantified engagement metrics, including participation in public lectures and “Ask Me Anything” series, will provide real-time feedback on BI efforts.

Reviewer 1: “The management team is gender balanced, but lacking of POC except in the ‘equity officer’ role.” LEAP’s ten-person Executive Committee is balanced in gender, and contains two people of color: Chief Equity Officer Cogburn and Corporate Engagement Director Burbano. However, we recognize the need for greater representation. As noted by Reviewer 1, any leadership team’s diversity should mirror society, and will otherwise be susceptible to racial bias, which can impact management and knowledge transfer potential. LEAP’s leadership team reflects general pipeline challenges in geoscience [2], which further necessitates our DEI strategy to make immediate and measurable progress in inclusion. Reviewer 1’s comment triggered extensive discussion across our team. While augmenting the leadership team in time for this report is not possible, we are committed to engaging the NSF and Site Visit Team in an important discussion on September 22nd.



6. KNOWLEDGE TRANSFER

Reviewer 3: “[LEAP] will fund an Executives in Residence program... This is an interesting idea, but how many executives have the time, energy, interest or ability to skip work for this?” Two of our Senior Personnel – Joppa (Microsoft’s Chief Sustainability Officer) and Newman (the Trust for Governors Island’s President) – committed to serving as inaugural Executives in Residence (EiRs), as a testament to their institution’s engagement. We recognize Reviewer 3’s concern though that this program requires a considerable time commitment, and that it may be difficult to recruit future EiR cohorts; thus, we decided to remove this program from the original scope. Corporate engagement and business research remain a commitment, and, in a Year 5 renewal proposal, LEAP may reintroduce this EiR program, contingent upon demonstrated interest and business engagement observed over the initial award period.

As part of our knowledge transfer with the private sector, LEAP’s website will provide climate data and information in multiple formats to make it useful and accessible to various stakeholders. While the exact nature of the data and information will be informed by company feedback, at a high level we expect this to include provision of raw datasets on climate outcomes, “translated” findings for practitioner audiences, and research-informed framing tools for effective communication of climate issues, to address the data and information needs of various types of corporate audience segments.

Panel Summary: “The proposal would have benefited [from] a clarification of the private sector connections.” Given the panel’s well-received concern that managing 27 institutional partners is potentially unwieldy, we will pare down our set of industry partners to include one company representative from each corporate audience segment from which we expect heterogeneous data and informational needs. In Year 5, we will reassess whether there is a need and demand for a larger set of corporate partners. These initial company representatives are:

Partnership	Company Type
Cubico	Sustainability-Oriented Investment Companies
PIMCO	Traditional Investment Companies
Google, Microsoft	Technology Companies
PepsiCo	Traditional Companies
FourTwentySeven	Sustainability-Oriented Start-Ups

Some of LEAP's industry partners will join the Knowledge Transfer Subcommittee, meeting monthly to define the format and nature of climate data that would be useful to different types of corporate audiences. In addition to obtaining information from partner corporations, LEAP will leverage collaboration from Columbia Graduate School of Business' Tamer Center for Social Enterprise and Bernstein Center for Leadership and Business Ethics to access national and international networks and conferences (in addition to the Northeast Big Data Innovation Hub's listserv). Through multivariate qualitative research, LEAP will gather broad perspectives on the format and nature of climate data that would appeal to different types of corporate audiences. LEAP will track our website traffic to understand what data and reports are most commonly accessed. LEAP's knowledge transfer initiatives will be deliberately bidirectional between researcher and stakeholder. Specifically, our website will include a feedback mechanism prompting users to indicate data/information usefulness, offering an opportunity to submit suggestions for what should be changed. The Knowledge Transfer Subcommittee will review this feedback quarterly to inform adaptation in our public and corporate engagement strategies and operations. We will summarize and communicate to the research team the information gathered from the annual survey/ qualitative interviews with private sector representatives. Anticipating the likelihood for contradictory feedback inputs, LEAP will conduct annual hybrid in-person/ virtual focus groups.

Reviewer 7: "Some mention is made in the proposal of such efforts, but I think it would be a benefit to the community to have LEAP share its successes and failures." Many of LEAP's broader impacts programs are themselves experiments that will supply data and knowledge for other interdisciplinary initiatives. As such, some programs will succeed, while others may not; even failures will allow for learning. We are committed to sharing our journey with the broad public. In Year 4, LEAP will prepare a manuscript describing its broader impacts experiments, particularly those within the proposal's Broadening Participation sections, and submit it for publication in a high-impact journal (e.g., *Nature Geoscience*).



7. ASSORTED COMMENTS

Reviewer 7: "[It] would have been nice to have seen more information about Google's... role in the STC." As a world leader in ML and cloud computing, Google will strengthen LEAP's core technology development, knowledge transfer, and educational initiatives. Several activities will foster collaboration: LEAP's Year 1 Kick-Off Meeting will include Google representatives, establishing and enabling tight institutional integration. Due to institutional co-location in New York City, Google will make LEAP student internship opportunities available, and LEAP will devote space for Google researchers to physically sit in center headquarters (committed in the Facilities Statement). We have already identified several possible Director-level collaborations at Google, including Sukthankar (on LEAP's Senior Personnel team) and others who lead ML and climate change teams. Finally, Google will provide unique computational and data resources via the Google Cloud Platform, allowing LEAP researchers to efficiently scale-up their science and technology via LEAPangeo. Since Pangeo has already deployed significant data and computing resources in Google Cloud, LEAP will continue this momentum towards climate data openness.

Reviewer 7: "Zanna is... embedded into leadership as the Geoscience Lead. I notice that she intends to draw 0.5mo funding... That does not seem like enough of a commitment for such a position." Absolutely. We commit to providing Geoscience Director Zanna with 1.5 months of summer salary, in line with Data Science Director Vondrick. We appreciate this recommendation.

Reviewer 7: "The External Advisory Board is an important component as well, though I might suggest additional expertise in Geoscience and in Data Science in advising the overall effort." **Panel Summary: "What is the rationale for including a 'CEO' on the External Advisory Board?"** LEAP establishes a six-person External Advisory Board to review an annual report, guide institutional partnerships, and provide the LEAP Leadership Team with management advice. Reviewer 7's comment prompted us to amend our plan: The revised External Advisory Board will now include seven advisors, and instead of the CEO will include two senior scientists in LEAP's convergent fields. We are confident this shift will allow for higher-quality research feedback and guidance in future Center operations.

Reviewer 2: “I wonder why Columbia’s CIESIN or NYU’s CUSP are not involved? They have substantial experience navigating this terrain.” Columbia’s Center for International Earth Science Information Network (CIESIN) and NYU’s Center for Urban Science and Progress (CUSP) are both leaders in applied data science, though both have a specifically regional/ local focus: CIESIN on regional sustainability, and CUSP on urban areas. LEAP addresses the global climate, and therefore our scope lies outside of these two centers’ focus.

Reviewer 2: “Not much international participation that I could discern.” Though Senior Personnel Bengio is a Canadian researcher, we interpreted the RFP as not requiring international participation. If this is an incorrect interpretation, we would be pleased to add new overseas personnel.

Reviewer 3: “LEAP will unite 48 researchers, five executive administrators, six academic institutions, two federal research labs, and 27 institutional partners... This seems rather wide ranging and ambitious.” **Reviewer 6: “The large number of partners seems an opportunity [and] a management challenge.”** LEAP is highly-ambitious, and we appreciate Reviewer 3’s caution. To further ensure that all programmatic goals are met, we hereby narrow the scope outlined in the proposal by “retiring” some efforts. This will additionally allow for reallocating budgetary resources towards new initiatives. The efforts from the proposal that we will remove include:

- The Executives in Residence program (Section 6);
- A cohort of industrial partners (Section 6);
- Microsoft *may* host its AI4Earth summit in New York City in LEAP’s second and fourth year, though this needn’t be committed at this stage due to the sheer complexity of organizing an international conference, plus the current pandemic’s unpredictability; LEAP will use its first year to ascertain demand and logistical feasibility for co-hosting this conference, and will update the NSF once a decision has been reached.



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