GAIA

2025 Problem Statement

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1. The GAIA Competition

Each year, the Global Action Impact Association (GAIA) hosts an annual, nationwide competition that welcomes college engineering students of all levels to prototype a solution that addresses global sustainable development needs. Teams work collaboratively to design, test, and refine their prototypes, tackling real-world challenges in areas such as clean energy, equitable infrastructure, and beyond.

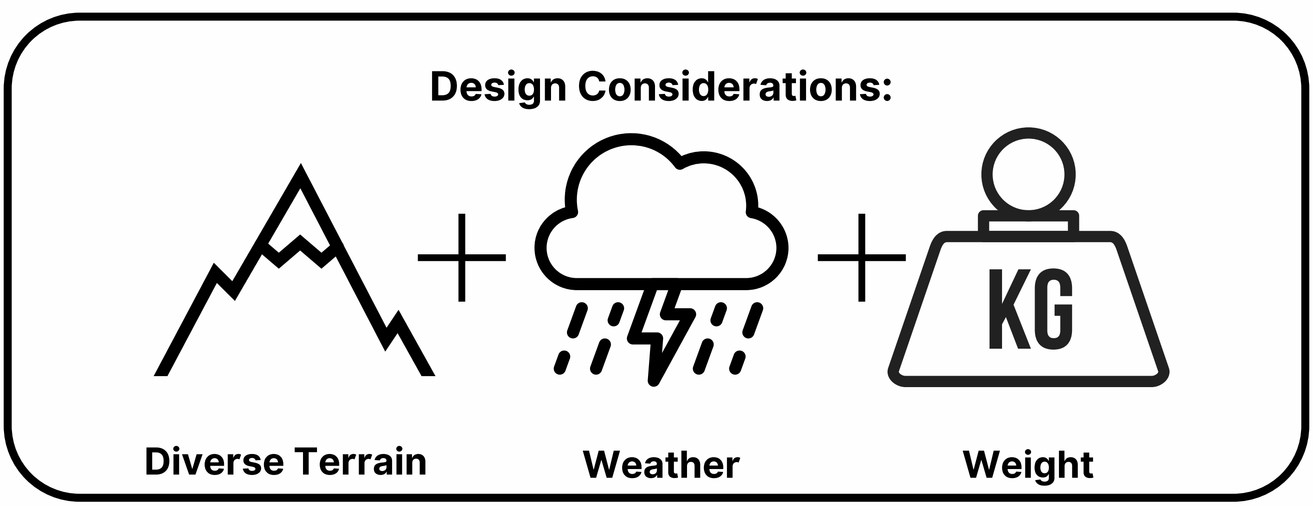
The competition emphasizes technical feasibility and social impact, encouraging participants to engage with affected communities, conduct rigorous testing, and consider realistic scalability in their designs. GAIA provides mentorship, technical resources, and access to industry professionals to guide teams through the development process, ensuring that their solutions are innovative and achievable within the competition timeline.

Beyond the competition, GAIA fosters a network of engineers, researchers, and change-makers committed to applying their skills toward global sustainability and equity. Participants gain hands-on experience in interdisciplinary problem-solving while developing leadership, communication, and project management skills. Winning teams often have the opportunity to refine and implement their solutions through partnerships with NGOs, research institutions, or industry sponsors. Through this initiative, GAIA aims to empower students to think critically about engineering's role in addressing pressing global challenges and to inspire long-term engagement in sustainable development efforts.

2. Problem Context

The United Nations Sustainable Development Goal 9 (UN SDG 9) addresses the need for resilient infrastructure, including sustainable transport systems that improve access to education, healthcare, and economic opportunities. However, for many regions of Latin America and Africa, reliance on non-motorized transportation remains prevalent due to economic, infrastructural, and urban planning challenges. **Walking accounts for approximately 30% of daily trips in major Latin American cities like Mexico City, Bogotá, and São Paulo, while in Africa, 78% of the population relies on walking as their primary mode of transport.** For lack of another option, walking is essential to accessing healthcare, school, and jobs for the majority of the population in these areas.

Bicycles provide a cost-effective, efficient, and environmentally sustainable solution to this challenge. By significantly reducing travel time and physical strain, bicycles enhance access to essential services, boost economic mobility, and support community resilience. **However, for bicycles to become a viable and widespread transportation alternative, they must be designed to withstand diverse terrain, weather conditions, and load capacities, ensuring they meet the practical needs of the populations they serve.**



To address these challenges, GAIA is partnering with World Bicycle Relief (WBR), an organization dedicated to empowering communities through mobility. WBR designs the Buffalo Bicycle, a purpose-built, durable bicycle engineered for rough terrains with minimal maintenance needs. GAIA teams will play a key role in advancing this mission by designing instrumented bicycle systems capable of collecting critical performance data on drivetrain efficiency, load impacts, terrain response, and rider comfort. This data will help optimize bicycle design for real-world conditions, enabling WBR to further improve the Buffalo Bicycle for the communities that need it most.

3. The WBR Program

The World Bicycle Relief (WBR) is a non-governmental organization (NGO) that empowers communities through mobility, providing specially designed, locally assembled bicycles to underserved regions globally. WBR's flagship product, the Buffalo Bicycle, is built for durability in harsh conditions and requires minimal maintenance, serving as a critical tool for accessing healthcare, education, and economic opportunities in rural areas.

GAIA teams will be challenged to contribute to the continued development of the Buffalo Bicycle through the design and implementation of an instrumented bike system to collect key performance data. The goal of this challenge is to inform future design improvements by measuring aspects such as drivetrain efficiency, load impacts, terrain response, and rider comfort.

A total of _ students from GAIA teams will be selected to participate in a WBR field deployment trip in Summer 2025, where they will test the winning design in real-world conditions. **The trip will be funded by GAIA**, covering lodging, meals, local travel, and bicycle modifications, while participants will be responsible for their flights. The exact travel dates will be determined based on student schedules and WBR's availability.

A competition in May will determine which team's sensor suite will be built and tested in the field. The selected team will work alongside WBR engineers to install and analyze the system's performance on Buffalo Bicycles in target deployment locations. The sensor suite would be installed on a few select testing bikes, and is not currently intended for inclusion on all Buffalo Bicycles. The present document, the Problem Statement, describes the technical requirements for sensor system designs.

*For more information on the scoring and structure of the competition, see the Competition Rules section.

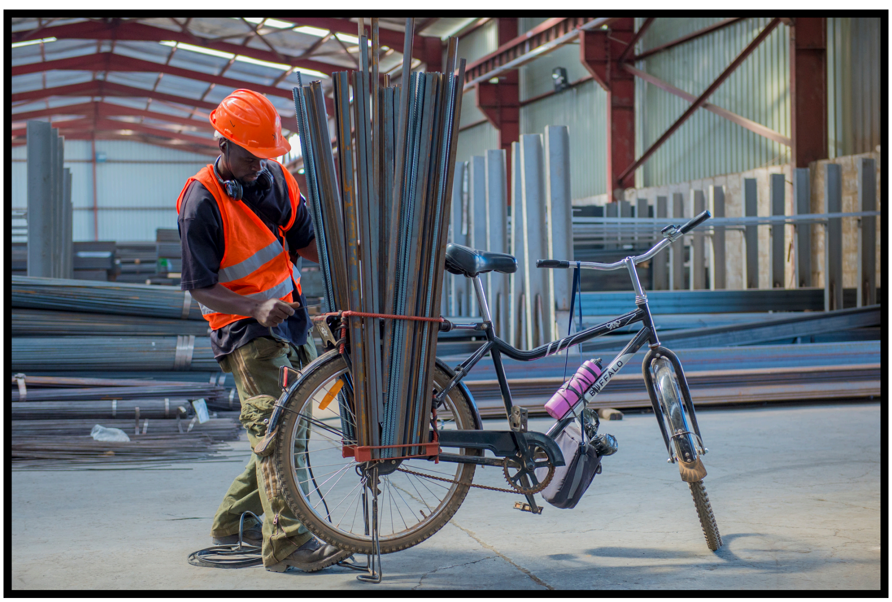
4. WBR Bicycle Design

The current S2 design features a multi-speed rear drivetrain for bicycles, allowing riders to access higher torque without the maintenance and robustness issues that come with a typical gear shift system. For more information, see the following websites:

- Maintenance Manual
- WBR Product Development
- S2 Product Page
- S2 Technical Highlights
- Patent for multi-speed drivetrain

The manufacturer of the S2 bicycle is Buffalo Bicycles. While competitors will not be creating a new bicycle design, understanding the current architecture and specifications of the S2 Bike will facilitate the design of a well-integrated sensor system.

The S2 CAD is available in IGES format at the following link, allowing teams to access more specific dimensions useful for interfacing such as frame tube diameters and bearing sizes.



5. Opportunities for Bicycle Redesigns

Table 1 shows potential future design improvements that WBR may want to make in the future, and what information/data is missing to inform those design changes. The GAIA problem statement is to design a sensor suite to collect that information/data. Table 1 informs the priority of collecting different types of data.

We emphasize that the specific sensor ideas here are just suggestions. Sensor types and locations can be potentially chosen creatively to provide direct or indirect insight on the desired information in a way that is easier to install or to avoid interfering with rider comfort and usability.

Teams are encouraged to refer to ISO standard 4210 for design guidelines, test procedures, and other relevant information (i.e. frequency range) for typical bicycles. ISO standards do not reflect the specific conditions of bicycle use in rural areas of underdeveloped countries, and WBR is interested in what discrepancies exist between GAIA's measurements and ISO values.

Table 1: Mapping Design Changes to Sensor Information

Subsystem to be redesigned	System Level Impact	What info is needed to inform a redesign	Importance of this info to inform redesign	Sensors that could provide that info
Drivetrain for improved lifetime and robustness (ie bearings, carrier)	High	Force histogram, speed histogram, number of cycles; identifying main contributors to wear and corrosion.	Force histogram and cycles (load profile) are critical for design. Wear and corrosion are harder to use to quantitatively drive design so less important	Axial and radial force sensors plus encoders that provide info on the motion of each shaft. Is there some way to measure the bearing friction over time - torque or even temperature delta? For wear and corrosion: humidity, salinity, dirt, and lubrication
Frame	Medium	Peak loads (axial, bending) on each frame tube and the seat post. Stress and strain.	Critical for design	Load cell, strain gauge.
Creating vibration profile to input to their vibration table, to inform fastener selection and possible addition of a vibration damping system	Medium	Vibration magnitude and frequency at different locations on the bike, including vibrations from ground terrain and from chain tension variation. Characterization of resonant frequencies.	Somewhat - they currently use a vibration profile for standard mountain bikes that does not represent the different terrain conditions of their riders.	Accelerometer; load cells or strain gauge with a high pass filter to isolate the reciprocating force
Improved rider comfort (ie saddle and seat post redesign, addition of suspension)	Low	Force imparted by ground, by frequency. Transfer function from ground force to seat displacement of the current bike.	Critical - would need to know the input spectrum to choose springs or dampers.	Load cells or strain gauges on the front fork and saddle post, and accelerometer on the saddle.

6. Design Requirements for Sensor System

1. Power: The power system of the sensor suite

a. The system should be rechargeable and cordless

b. If the power system requires recharging on the grid, the system must last at least 20 hours before a recharge is required.

c. Systems that do not require recharging on the grid (ie solar or pedal power) are welcome.

2. Lifetime: The system must be able to survive in the local environment

a. Consider moisture, temperature, vibration, and dirt/dust

b. The system should last through a full year of testing on rough terrain

c. Possible testing locations include Kenya, Colombia, and Zambia

3. Supply Chain

a. Sensors may be purchased and assembled in the United States.

b. A manual should be provided for installation and troubleshooting on the bike in country

4. Sensors

a. Sensors should be able to measure, at minimum, the following quantities:

i. Loads in the front fork of the frame and the saddle post

ii. Acceleration/vibration at the drivetrain and saddle

iii. Time (absolute), such as through a real time clock (RTC)

iv. Location, such as through a GPS Rotation on shafts of bicycle: pedals, each wheel, and steering column

v. Drivetrain torque, both at the input to the drivetrain (pre bearings, applied by user on pedals) and the output (post bearings, creating useful tire torque).

vii. Additional sensors may be added as desired based on the useful measurement quantities described in Table 1.

b. Competitors should decide reasonable values for each of the following values for each sensor; justify those decisions with calculations, estimates, and/or standard practices as needed; and explain their decision process in the documentation.

i. Maximum and minimum data value ranges

ii. Bandwidth: How frequently must each data stream be read from the sensors? How frequently must each data stream be logged?
iii. Precision: discretization level of the sensor output itself, the monitoring electronics, and the data logging. Noise amplitude and signal-to-noise ratio.
iv. Accuracy: absolute and relative error including static offset and slow drift over time.
v. Filtering: should data be filtered before logging, and if so with what time constant?
vi. Data transformation: should data be transformed (ie from time to frequency domain) before logging, and if so with what algorithm or formula? Note that transforming vibration data from the time domain to the frequency domain can eliminate useful information such as peak amplitudes and kurtosis, so this should be addressed.

5. Data must be easily exportable and interpretable

- The system must be able to be installed onto the bike in <1.5 hours by mechanics using limited standard hand tools. Access to pliers, hammers, pipe wrenches, anvil, and screwdrivers can be assumed. Allen keys are not available, so bolts must be Hex heads or Phillips heads.
- Mechanics will not have access to the internet, computer, or phone service.
- Data logging is only needed while the bike is being ridden. While the bike is not in use, the system is permitted though not required to shut down to conserve power and memory. Shutdowns must not affect the accuracy of system timestamps.
- The system must include an “event button” in an easily accessible location such as the handlebars. Riders will press it to indicate anything unusual that they want to mark in the data, such as a mechanical failure or change in performance. Events should be visible in the logs for contextualizing other data.
- In the event of an error in the data logging system (such as a sensor becoming disconnected or consistently reading unviable values), the system should notify the rider via an indicator light. Further tools for debugging (i.e. error codes) could be helpful and are up to the team's discretion to implement.

- Sensor packaging
  - Sensors should not majorly affect the bike's performance. Sensors must be located in a position that does not affect the way the rider interacts with the bike. In particular, the sensors should not affect the way riders grip the handlebars, sit on the seat, position their legs/feet during pedaling, or store objects on the rear carrier.
  - Sensors may be placed under the rear carrier but not on top of it or to the sides of it to ensure full access to the carrier, as testers may carry test loads.
- Cost: The sensor suite should cost no more than $500/bike, including both initial and maintenance costs.
- Software: open source software is preferred but not required.
- Quantity: Systems aren't expected to be mass-producible, but reputable and consistent. Expect a final production volume of 20 units.

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7. Scoring

Sensor suites will be scored on a combination of what data they measure, data validity, durability, usability, and cost.

Before the competition, teams will submit documentation describing the system. Some documentation should describe the design choices with an audience of engineers, while other documentation should be instructional (i.e. installation and maintenance) with an audience of mechanics. The documentation will be scored on the following criteria (55 points total):

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Table 2: Breakdown of Pre-Competition Scoring

Category	Criteria	Possible Points
Information	Is there enough information that the system can be fully recreated by others?	**10**
Communication	Do the structure, explanation clarity, and visual aspects of the documentation make it easy to navigate and understand?	**10**
Professionalism	Does the documentation look neat (ie alignment, formatting) and is it free of spelling/grammar errors.	**5**
Cost	How expensive is the system, based on the bill of materials? Points awarded on a linear scale where the team with the cheapest design receives 10 points, the most expensive design receives 5 points, and designs exceeding the $500 maximum receive no points.	**10 / 5 / 0**
Data Context	Do the sensors chosen provide the desired information, and has thought been given to the tradeoffs?	**20**
		TOTAL: 55

Table 3: Breakdown of At-Competition

Scoring Category	Criteria	Possible Points
Usability	At the competition, a GAIA/WBR representative with no prior knowledge of the team's system will install the sensor suite on a WBR bike. Score will be assigned based on the required duration and perceived ease of installation.	**10**
Resilience	A rain and dust test will be performed by judges to ensure survivability, and the bike will be ridden on a pre-determined off-road course at Cornell. This portion of the competition will be scored as simply pass or fail, based on whether the sensor suite survives the test. Systems that fail will be permitted to retry for half credit at the judges' discretion	**20 / 0**
Data Quality	After the ride, sensor data will be extracted and teams will be scored on the data quality. Points will be deducted for signal dropout and noise/inaccuracy exceeding specifications. The exact formula will be announced in March.	**50**
-	-	**TOTAL: 80**

The total possible score for pre and at-competition scoring will be 135 points. More details on the exact test conditions and scoring criteria will be described in future releases.

8. Recommended Timeline

The following table is a suggested timeline by the GAIA organizers for completing the competition by the weekend of May 3. Teams are encouraged to work ahead of schedule as they see fit, but this serves as a framework for key deliverable dates that should be met for prototype completion by competition day.

Task/Actionable	Start Date	Recommended Work Length (weeks)
Partner and topic announced Lit review and	Dec. 4	-
background research Problem statement	Dec. 4	-
released Read challenge; architecture and	Feb. 22	-
conceptual design	Feb. 22	1
CAD released	Mar. 1	-
Detail design (CAD, analysis, sourcing)	Mar. 1	3
Purchase materials (ie sensors, wiring) for prototype and manufacture parts (ie brackets)	Mar. 22	1
Assemble prototype	Mar. 29	1
Debug and troubleshoot prototype	Apr. 5	2
Collect test data for prototype	Apr. 19	1
Work on written deliverables	Apr. 26	1
Competition	Weekend of May 3	-

By the conclusion of the 2025 GAIA competition, teams will have a sensor suite capable of collecting data and insights to lay the groundwork for future design iterations.