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Experience Report on the Prototyping of a Mobile System for Geomagnetic Storm Forecasting: Challenge-Based Learning

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Resumo. *This study, conducted as part of the NASA Space Apps Challenge, exemplifies Challenge-Based Learning, allowing students to develop innovation skills while addressing the significant risks of geomagnetic storms to global electronic infrastructures, which have potential economic impacts of \$2.6 trillion. Utilizing a Long Short-Term Memory (LSTM) neural network, we analyzed data from the DSCOVR satellite, navigating its limitations. Our methodology entailed developing a Solar Classification (SC) index from the Z component of the magnetic field (Bz) to address data inconsistencies. We trained the LSTM with 80% of the refined dataset and validated it with the remaining 20%, achieving a Root Mean Square Error (RMSE) of 0.8724%. This research, arising from a collaborative and competitive educational setting, highlights the effectiveness of team-based approaches in tackling complex scientific challenges and demonstrates the potential of AI in improving space weather forecasting and enhancing public preparedness readiness.*

Keywords: Challenge-Based Learning; DSCOVR; Geomagnetic Storm.

1. Introduction

As highlighted by Biggs e Tang (2003) and Gomez-del Rio e Rodriguez (2022), university teaching techniques evolve as educators strive to simultaneously achieve two key objectives: high-quality learning and more effective teaching. Historically, engineering education favored a professor-centric approach. However, this traditional model is being updated with methods aimed at enhancing knowledge acquisition through active student participation in the teaching-learning process. In this model, greater student motivation can be achieved using various learning methods, such as Project-Based Learning (PjBL), Problem-Based Learning (PBL), gamification, flipped classroom, case-based teaching, discovery learning, on-demand teaching, among others. (CHI; WYLIE, 2014; BALLESTEROS et al., 2021; Gomez-del Rio; RODRIGUEZ, 2022)

Another example of an active learning method successfully implemented in engineering education is Challenge-Based Learning (CBL). Rooted in earlier methodologies like collaborative

Problem-Based Learning (PBL), CBL enhances many of PBL's benefits. Its distinct feature lies in presenting students with real-world challenges that are more complex than standard classroom projects. CBL integrates phases of learning, providing both theoretical and practical knowledge, and culminates in challenges with defined outcomes. (LÓPEZ-FERNÁNDEZ et al., 2020)

Based on the work of López-Fernández et al. (2020), it is clear that CBL has a significant positive impact on student motivation. Their research highlights improvements in intrinsic factors such as motivation, self-confidence, and a sense of accomplishment, as well as in extrinsic motivators like the academic environment and perceptions of professors' performances. Additionally, López-Fernández et al. (2020) found that the professor-student relationship was notably enhanced, with students showing greater appreciation for their professors after collaborating on challenges, leading to a more engaging and productive dynamic. The learning process as a whole benefited from CBL, not only in terms of boosting student motivation and improving the professor-student relationship but also in achieving educational objectives, acquiring knowledge, and enhancing both technical and soft skills. However, the implementation of CBL was not without challenges, as López-Fernández et al. (2020) noted concerns from professors regarding the need for more resources and from students about adapting to a more active and collaborative learning style.

The work of Senghore et al. (2015) provide a comprehensive analysis of hackathon-style events, like NASA's International Space Apps Challenge, as prime examples of Challenge-Based Learning (CBL). According to research of Senghore et al. (2015), these events not only serve as effective platforms for user innovation networks but also distinctly showcase the role of CBL in driving innovation. Senghore et al. (2015) further elaborate on the relationship between competition and innovation output, indicating that the competitive environment inherent in hackathons fosters an atmosphere conducive to innovative thinking and breakthroughs. This environment, characterized by a healthy rivalry, encourages participants to excel and outperform, thus acting as a significant catalyst for innovative developments and advancements.

In this regard, the primary aim of this paper is to present an experiential report on the outcomes achieved by students, who are in the early stages of their undergraduate studies, in the NASA Space Apps Challenge 2023 competition.

2. Problem Statement

Established in 2012, the NASA Space Apps Challenge has grown to be the largest annual global hackathon, attracting participants from various backgrounds. The event recognizes top projects as Global Winners, highlighting its focus on innovation. More than a competition, Space Apps is about encouraging collaboration and building a community. The challenge aims to promote collaboration, creativity, and critical thinking, as well as to spark interest in Earth and space sciences. It also aims to increase awareness of NASA's data and support the development of the next generation of scientists, engineers, and designers. (NASA Space Apps Challenge, 2023b, 2023c)

For 2023, the theme of the Space Apps Challenge is "Explore Open Science Together" reflecting a dedication to shared research and learning. This year features 30 challenges, created by NASA's Subject Matter Experts (SMEs), offering a wide range of topics for participants. These challenges are intended to inspire creative problem-solving and innovation, and to invite participation from various fields. The primary goal is to foster an inclusive environment where open science serves as a key element, bringing together emerging scientists, engineers, technologists, and designers in a joint effort of discovery and learning. (NASA Space Apps Challenge, 2023b, 2023c)

The chosen challenge for our group focuses on utilizing the "raw" data from NOAA's Deep Space Climate Observatory (DSCOVR) to predict geomagnetic storms on Earth. Despite DSCOVR operating beyond its expected lifetime and experiencing occasional faults, these faults may provide valuable insights into space weather conditions. Geomagnetic storms, caused by solar wind interacting with Earth's magnetic field, pose significant risks to technologies like GPS and power grids. DSCOVR's unique position at the Lagrange point 1 enables it to measure solar wind properties, which are crucial for forecasting these storms. (NASA Space Apps Challenge, 2023a)

3. Experience Report

To undertake the challenge, two main activities were conceived: i) Data: engage with the data provided by the competition; ii) User Interface: develop a method to present the data in a user-friendly manner to the relevant stakeholders, including Electric Grid Operators, Space Systems Operators, Airlines, Telecommunication Providers, Astronauts, and the General Public. The total time allocated for developing a solution to the challenge was approximately 30 hours.

3.1. Data

Engaging with the data presented a significant challenge, particularly in terms of interpretation. A key aspect of our endeavor involved deciphering the data, especially concerning the Faraday Cup. Due to difficulties in comprehending this aspect, the focus shifted towards calculating the Kp index. This shift in approach was guided by insights from reference (GONZALEZ-ALARCON et al., 1994), which elucidated the correlation between the Z component of the magnetic field (Bz) and the Kp index (Space Weather Prediction Center, 2023).

In our approach, we conducted a comparative analysis between the data of the Z component of the magnetic field (Bz) as detailed in source (NASA Space Apps Challenge, 2023a) and the Kp index data referenced in source (Kp Index, 2023). It was observed that on instances where Bz values were less than -10, there was a corresponding elevation in the Kp index. Following the validation of this correlation, we proposed the development of a Solar Classification (SC) index, which would focus exclusively on the Bz component of the magnetic field data provided, as shown in Table 1. The correlation between the Bz measurements and the SC index, based on the data available at this stage, is depicted in Figure 1.

Table 1. Solar Classification (SC) index

Bz	SC	Classification by Gonzalez-Alarcon et al. (1994)
$Bz > -3$	0	-
$-5 < Bz \leq -3$	3	Small
$-10 < Bz \leq -5$	6	Moderate
$Bz \leq -10$	9	Intense

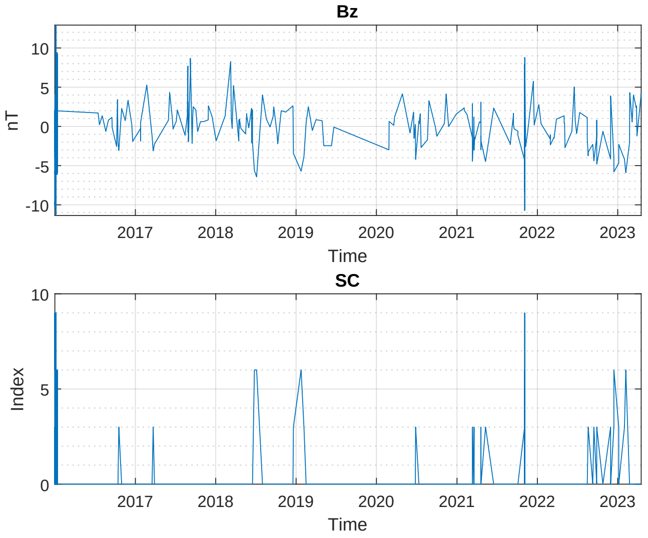

Figure 1. Correlation between the Bz measurements and the SC index.

3.2. Forecast

Based on the insights garnered from sources (MURALIKRISHNA; SILVA; LAGO, 2008; NASA, 2023), we opted to employ a Long Short-Term Memory (LSTM) network for the purpose of forecasting. In line with this methodology, 80% of the dataset was allocated for training purposes, while the remaining 20% was reserved for validation.

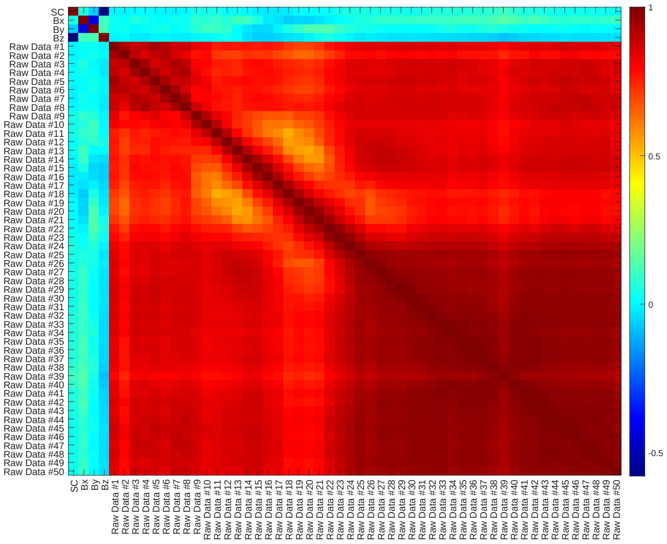

Figure 2. Correlation between data (NASA Space Apps Challenge, 2023a) and SC.

Upon analyzing the available data in conjunction with the Solar Classification (SC) index, a discernible correlation was observed. This relationship is illustrated in the Figure 2, where the intensity of darker shades is indicative of a stronger correlation. In this representation, the x-axis and y-axis (beginning from the second value) correspond to the columns from the spreadsheet provided in source (NASA Space Apps Challenge, 2023a). The first row and column in the Figure 2 represent the computed SC index values.

Consequently, the decision was made to exclude the data derived from the Faraday Cup in our analysis. Specifically, “Raw Data” in Figure 2, which represent the values from the Faraday

Cup, were discarded. This strategic exclusion, coupled with the removal of data entries containing 0 or NaN values, effectively reduced our total sample size to 5790. Therefore, the Bz index was utilized as the input variable, and the proposed SC index served as the output variable in our model.

The configuration details of the LSTM network architecture are delineated in Table 2.

Table 2. LSTM configuration

Parameter	Value	Description
numFeatures	1	Inputs.
numResponses	1	Outputs.
numHiddenNeurons	200	Number of neurons.
Epochs	200	The number of times the entire dataset will be passed forward and backward through the neural network.
miniBatchSize	1	The size of the data chunks that the network will see in one go.
LRDropPeriod	100	How often (in terms of epochs) the learning rate will be reduced.
InitialLR	0.01	The initial learning rate.
LRDropFactor	0.1	The factor by which the learning rate will be reduced.
valFrequency	30	How often the network validation will occur.

Figure 3 displays forecasts for the magnitude of geomagnetic storms, in alignment with the classifications outlined in Table 1. The forecast error, computed using Equation 1, is determined to be 0.8724

$$E_{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[(y_{(i)} - \hat{y}_{(i)})^2\right]}. \tag{1}$$

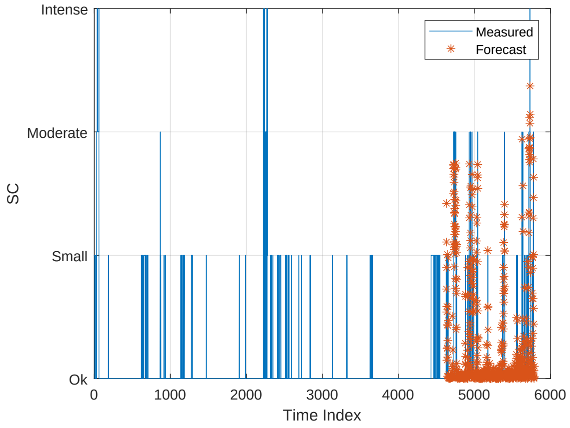

Figure 3. SC Forecast

3.3. APP

The design of the application [1] was conceptualized to facilitate users in receiving alerts, enabling them to make informed decisions. Recognizing that domain-specific information can be complex for non-experts, the app is tailored to present this information in a more accessible and user-friendly format. This approach is intended to broaden the app's usability to include ordinary users, making it more inclusive and practical for a wider audience.

The main screen of the application, as shown in Figure 4, features several options designed for user interaction and accessibility:

- Profile: This section pertains to the user's personal data.
- Satellite: This option provides detailed information about the DSCOVR satellite.
- Forecast: Displays real-time measurements relevant to geomagnetic activities.
- Alerts: In the event of a storm alert, users will receive notifications, along with an estimated time frame to make decisions.
- Exit: This function allows the user to close the application.

Figure 4. Main screen.

Each option is structured to offer comprehensive and relevant information, ensuring a user-friendly experience for effective decision-making.

Within the user profile section of the application, individuals have the option to select their user category based on specific needs, as shown in Figure 5. The available categories are:

- GPS: For users primarily concerned with Global Positioning System-related information.

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[1] Available on: https://www.figma.com/proto/3eePmstZHNKLEqraKklrKn/Untitled?type=design&node-id=18-21t=WilZRkDU48glJm5R-1&scaling=min-zoompage-id=0%3A1starting-point-node-id=18%3A21

- Electric Grid: Tailored for professionals or entities managing or relying on electrical grid systems.
- Global Positioning System: A dedicated category for users needing detailed GPS data.
- Gas Pipeline and Oil Pipeline: For those involved in the management or use of gas and oil pipeline infrastructures.
- Air Traffic Control: Aimed at air traffic control professionals requiring precise and timely geomagnetic storm information.
- Radio Communication Network: For users in the field of radio communication, where geomagnetic activities can have a significant impact.
- All: An option for users who require comprehensive information across all categories.

Figure 5. User category screen.

This customization feature allows users to receive tailored information and alerts relevant to their specific domain or area of interest.

On the forecast screen, as illustrated in Figure 6, users are able to view the measurements recorded in the Bz index along with the estimated SC index. These data are generated and displayed in real-time, immediately following the provision of information by the satellite. This feature ensures timely and accurate access to crucial data, aiding users in understanding current geomagnetic conditions and potential storm forecasts.

Recognizing that interpreting graphs may require a certain degree of familiarity with the data, an additional feature has been included in the application to enhance user accessibility. This feature presents the classification of geomagnetic storm intensity directly, using straightforward categories: Small, Moderate, and Intense, as shown in Figure 7. This approach simplifies the understanding of the data for users who may not have specialized knowledge, ensuring that the information is accessible and easily comprehensible to a broader audience.

Figure 6. Forecast screen.

Figure 7. Storm classification Screen.

In the event of a storm, the application features an alert system that includes a color change. This color alteration is designed to flash, providing a visual cue to the user, as demonstrated in Figure 8. This blinking color change is implemented to draw immediate attention to the alert, ensuring that users are promptly informed about potential geomagnetic storm conditions.

Figure 8. Geomagnetic storm alert.

4. Conclusions

The experience gained by students in the NASA Space Apps Challenge 2023 was invaluable, especially in applying Challenge-Based Learning to a real-world problem. The primary focus of our team was to predict geomagnetic storms using data from NOAA's Deep Space Climate Observatory. This task not only challenged our technical skills but also deepened our understanding of data analysis and interpretation.

A significant achievement of our project was the development of an application designed to present complex geomagnetic data in a user-friendly format. This application, tailored to a diverse range of users including Electric Grid Operators and the General Public, showcases the importance of user-centered design in technology development. The ability to categorize and present data in an easily understandable format, such as the classification of storm intensity into categories like Small, Moderate, and Intense, was a key aspect of making scientific data accessible and actionable.

Furthermore, the utilization of a Long Short-Term Memory (LSTM) network for forecasting presented a learning curve. The network, trained with 80% of the data and validated with the remaining 20%, achieved a forecast error of 0.8724%. This outcome not only demonstrates the effectiveness of machine learning in data prediction but also highlights areas for improvement in future iterations.

Overall, the challenge provided a comprehensive learning experience, from understanding the intricacies of space weather to developing a practical tool for data interpretation and public dissemination. It underscored the importance of interdisciplinary collaboration and the integration of technical knowledge with practical application. The experience has undoubtedly equipped the participating students with skills and insights valuable for their future academic and professional endeavors

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