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Board 214: Building an Understanding of Black Families' Engineering, Design, and Inventive Practices

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Abstract

Black students belong in STEM career pathways but often experience a diminished sense of belonging in their college programs. Through informal conversations, the authors learned that some Black students felt they had not had the formal pre-college engineering training and extracurricular experiences that they perceived their peers had and therefore they did not feel they possessed engineering knowledge. There is little research that identifies the diverse engineering family practices of Black families and further finds ways to connect these practices to formal higher education learning environments. Acknowledging the rich history of Black engineering, design, and invention that occurs in Black households and communities, the authors explore the following question: In what ways can engineering practices emerge as Black families engage in design challenges?

This study is informed by asset-based frameworks and a systems theory of learning to center the role of the Black family in learning how to engage in and value engineering, design, and inventive practices. To date, 15 Families have participated in activities that were modified from the Invention Convention Curriculum. Their design sessions were video recorded and were analyzed using Python and qualitative methods. This work-in-progress manuscript will focus on identifying the engineering practices of one family who participated in a set of family engineering design activities. The authors will share insights from the family narrative (synthesis of all the data generated from the family’s participation) and results of how the family enacted specific engineering practices. Also, the authors will share a preliminary reflection on how these practices might serve as a vehicle to positively impact the sense of belonging of Black engineering students.

1 Introduction

The academic success of Black students is linked to the familial cultural capital. The family model has been employed as a means of helping students adjust to the rigors of higher education [1]. Positive effects on academic accomplishment are produced when a child's academic endeavors are supported by their family [2]. Familial capital shows up in the form of motivating the student to keep trying, expressing joy in their achievements, endorsing STEM as a desired career path, sharing perseverance stories, and establishing standards for academic excellence and deference to professors and instructors [3]. Despite the impact of STEM exposure and culturally relevant informal learning experiences within families, little is understood about the engineering practices that emerge when Black families and communities engage in STEM, inventive, and engineering design activities with their children.

By placing the Black family at the core of learning and innovation and employing asset-based frameworks and systems theory of learning, this study challenges deficit narratives and highlights the contributions that Black families make to the STEM fields. The findings of this study will advance our understanding of how Black families engage in design, nurture creativity, and foster a sense of belonging among students through family STEM activities. Future work will create effective bridges between Black Family STEM life and STEM classroom and college experiences to address the sense of belonging along STEM academic pathways.

2 Literature Review

STEM education is more crucial than ever since it gives people the information and abilities needed to think critically [4]. Studies, however, consistently show that Black families are underrepresented and have limited participation in STEM education [5]. The lack of diversity in STEM is sometimes attributed to various obstacles in STEM fields that underrepresented students still face despite ongoing intervention measures [6]. These obstacles include late exposure to STEM career pathways, overrepresentation of historically underrepresented students in under resourced school districts, implicit biases in the educational system, socio-economic barriers to participation in extracurricular activities, a lack of easily accessibly STEM role models, historically unwelcoming academic culture in STEM disciplines, and low perceptions of the aptitude and drive by educators along their educational [7,8].

Past research has provided evidence that intentionally introducing black students into STEM from an early age can increase their motivation, self-efficacy, and perseverance in STEM field [9]. Additionally, culturally relevant approaches help African American students succeed academically in K–12 settings [1]. Despite these, students from marginalized groups, particularly Black students often struggle to feel included in College STEM programs and some students still have limited access to robust STEM experiences [10]. Many believe they do not have the same rigorous pre-college engineering instruction and extracurricular activities as their peers. These limitations often lead to underrepresentation in STEM, the feeling of being underprepared for STEM college experiences and lower career expectations [11,12].

Diversity, equity, and inclusion in STEM fields results in enhanced creativity, problem solving, innovation and increased cultural competence, making this a crucial opportunity and challenge for educational institutions, legislators, and society at large [5]. To achieve and expand diversity in the engineering workforce, scholars and practitioners have emphasized a focus on addressing lower recruitment and retention rates of engineering students from minority groups in higher education [13,14]. Various intervention strategies such as creating inclusive and welcoming STEM environments, summer bridge programs, mentoring, hands-on learning experience, tutoring, career counselling and awareness, learning centers, workshops and seminars, academic advising, financial support, targeted at underrepresented groups are being implemented to improve diversity in STEM [12, 15, 16]. These interventions yield positive outcomes as evidenced by improvements in the grades of participating students.

Despite previous interventions' impact on grades earned, Black students still experience a lack of sense of belonging in STEM. Black students often draw upon social capital and familial capital to persevere in STEM fields as documented in asset-based scholarship. The advocacy and encouragement from family, school, and community that encourage and inspire active participation in STEM are vital in helping Black students enter and remain in STEM [17]. A supportive family-like environment has been shown to boost undergraduate interest in STEM, enhance academic performance, and produce favorable opinions of faculty mentoring [1]. Engagement between Black students and faculty members in different activities play an important role in the persistence of Black students in STEM [18,19].

Familial capital shows up in the form of motivating the student to keep trying, expressing joy in their achievements, endorsing STEM as a desired career path, sharing perseverance stories, and establishing standards for academic excellence and deference to professors and instructors [3]. Black families play an immense role in developing and sustaining their children's interest in engineering by fostering curiosity, providing resources, encouraging hands-on experiences, promoting collaboration, cultivating problem-solving skills, offering emotional support, creating a supportive home environment, and engaging with the wider engineering community [2]. Previous studies demonstrate the role the family plays in influencing various facets of students' academic lives such as perseverance in learning, selection of school, and choice of major [14].

Black families are critical sources of familial capital and engineering learning partners for their children [2]. Studies have found that African American parents actively advocate for their children's education and contribute to fostering their interest and success in STEM fields, serving as mentors and first teachers, providing a supportive environment, constant encouragement, educational resources, and seek out extracurricular activities that promote STEM learning [20, 21]. This support is crucial for enabling Black students develop a sense of belonging in STEM [18]. The feeling of belonging contributes to persistence in completing a degree in STEM [22, 23].

STEM activities in Black communities increase access to cultural and recreational enrichment, strengthen bonds between participants, increase participation in STEM fields, and develop a sense of agency and belonging [24]. The lack of sense of belonging in STEM experienced by Black students diminishes the recognition of beneficial engineering practices ingrained in Black families' everyday lives and cultural traditions. To address this, the current study aims to validate and celebrate the STEM-related competencies of Black families as they engage in design activities in informal settings. This study seeks to understand the diverse engineering, design, and creative practices that emerge within Black families as they tackle STEM-related design challenges. The central research question is: *In what ways can engineering practices emerge as Black families engage in design challenges?*

3 Methodology

Children's learning and development are greatly influenced by their interactions with family members, especially in activities that involve hands-on experiences [25]. Engineering design activities completed in informal learning settings provide valuable opportunities for children to collaborate with their family members in ideating, designing, building, testing, and communicating design ideas, thereby fostering meaningful interactions that can support the child's cognitive, social, and emotional growth.

3.1 Context

To explore the complex engineering practices that emerge as Black families engage in the design process, the authors presented a series of design challenges from the Invention Convention Curriculum [26] to involve 15 Black families in an informal setting. Families are invited to complete a 60-minute design challenge where they are given a design brief and prototyping materials, they must build and test a low-fidelity prototype and must complete the challenge with a design pitch. Multiple families participated in each session.

3.2 Design Activity

The design problem was of a logistics company needing a faster and efficient means to deliver products to their customers. Families were to design a low-fidelity air drone to help in the safe delivery of fragile products to customers. Each phase of the ideate, design-build-test-communicate process was timed. Families were notified when to move on to the next stage of the design process. An egg was used in the testing process to determine if the designed product worked to safely deliver fragile objects (an egg) from a height of 2 meters. A good prototype would be easy to open with the egg unbroken after testing.

The design session lasted a total of 45 minutes allowing the families to work together to solve the given problem. The task was meant to be both engaging for the students and adult family members, promoting creativity, problem-solving, and teamwork. Basic building materials like cardboard, tape, and simple tools were provided for the design challenge.

Initially, families received a brief introduction to the session that included a summary of the challenge, safety guidelines, and a list of resources that were accessible. After that, they were split up into smaller groups, each made up of families. There were facilitators on hand to help participants with the challenge, respond to inquiries, and offer support as required.

3.3 Participants

Participants in this study were Black families with at least one child who was between the ages of 10-12 years old. The participants decided who counted as family and the research team did not restrict participation of additional family members once it was determined that atleast one guardian and child (aged 10-12 years old) identified as Black or African American. The participating families were recruited from local middle schools that were hosting family STEM nights, from online Facebook advertisements, and from known family networks. All the participants live within the same geographic region. The nature of the study, including the use of facial mapping and video capture for data processing, was explained to the participants. Anonymization of data and the option for participants to opt out of recording at any moment are the steps taken to guarantee privacy and confidentiality. The research was authorized by the institutional review board (IRB) to ensure adherence to ethical standards in research involving human subjects.

Family 1: In the video being analyzed to explore the dynamics of family engagement and interaction within STEM a 7th grade girl and her grandmother are the focus of our investigation. In Figure 1, the grandmother and daughter were seen brainstorming ideas during the IDEATE phase of work.

Figure 1: Brainstorming Ideas

Figure 2: Building

In this manuscript, the experiences of a single family were selected for a narrative synthesis, providing a rich and detailed account of their engagement in the ideate-design-build-test-communicate activity. This approach offers understanding of how a specific family navigates and participates in the activity, shedding light on the unique dynamics and interactions that unfold. By highlighting the engineering design techniques utilized by this family, we can glean valuable insights into the ways in which family members and children collaborate, communicate, and problem-solve within the context of the ideate-design-build-test-communicate activity. The narrative synthesis delves into the family's journey through the activity, documenting their collaborative efforts, the exchange of ideas, and the supportive interactions that shape their engagement. By focusing on a single family, we can capture the intricacies of their communication patterns, decision-making processes, and the emotional dimensions of their interaction. This personalized narrative adds depth to our exploration of family-child engagement in hands-on activities, offering a compelling glimpse into the positive outcomes and learning opportunities that emerge from such collaborative endeavors.

The inclusion of specific engineering techniques further enriches the narrative, showcasing the creative problem-solving approaches and innovative thinking employed by the family. By drawing attention to these techniques, we can elucidate the ways in which the ideate-design-build-test-communicate activity fosters not only technical skills but also cognitive development, creativity, and critical thinking in children through meaningful family engagement.

3.4 Data Collection

Following written consent by the participants, video recording of the design session served as the main means of data collection. To record family interactions, use of the materials, and general involvement in the activity, cameras were positioned strategically. Video data provides comprehensive and dynamic information on verbal and non-verbal communication patterns of collaboration, and the application of STEM concepts between family members and the students.

3.5 Data Analysis

The video data gathered for the design activity provides an excellent opportunity to delve into the intricacies of family-child verbal, and non-verbal interaction, throughout the design activity. Through qualitative analysis and facial mapping using python, we hope to gain valuable insights into the dynamics of these interactions, enabling a more comprehensive understanding of the influence of family engagement on children's learning and development of STEM interests as Black families work as a team to perform a design task. The qualitative analysis of the video data will allow us to identify patterns of communication, collaboration, and support between family members and children during the design activity.

Facial mapping captures non-verbal cues and emotional expressions, shedding light on the affective dimensions of these interactions. By leveraging this video data and employing rigorous analytical methods, we can enrich our exploration of the significance and outcomes of family-child STEM interaction in informal spaces. The scripts utilized open-source facial recognition and mapping libraries to identify and categorize emotional expressions during the session.

Thematic analysis was employed in qualitative data analysis to detect recurring themes and patterns in family relationships and their involvement with the STEM challenge. Researchers with training in qualitative methodologies analyzed the video recordings and classified the information using pre-established categories for problem-solving techniques, interaction, and teamwork.

Python was used to evaluate the facial mapping data and assess the participants' emotional reactions to the activity. Through the identification of expressions, the study was able to shed light on the participants' emotional journey through the STEM design challenge. Combining quantitative face mapping with qualitative observations will allow for a thorough knowledge of how family-based STEM activities affect learning, engagement, and emotional experience.

3.5.1 **Analysis using Python.**

To delve into the family-child relationship throughout the design activity an engagement prediction model was developed on a large dataset and then tested on the video data to validate the accuracy of the model and prove its usability in real life applications. The following steps were taken to perform the data analysis:

3.5.1.1 **Exploratory Analysis**

The dataset used to train the model is the 2013 Facial Recognition dataset (FER-2013). The dataset is provided by Kaggle a platform where users share datasets, code and participate in competitions. The dataset was introduced at the International Conference on Machine Learning (ICML) in 2013 introduced by Pierre-Luc Carrier and Aaoron Courvill [27]. The dataset consists of 28,709 training images and 3,589 test images, each of the size 48x48 pixels. The images in this dataset are categorized into seven facial expressions also called classes: anger, disgust, fear, happiness, sadness, surprise, and neutral. And although we will train the model in all those 7 classes, the main classes for our study are happy, sad, surprise, and neutral. The data analysis was performed on python over a wide range of libraries including: Numpy, Pandas, Matplotlib, Seaborn, Scikit-learn, TensorFlow and OpenCV. These libraries were imported for data handling, visualization, and model development.

3.5.1.2 Data Visualization

To better understand the data and see the differences between the classes. Through visualizing the images, we noticed the image shape to be (48,48,3) allowing us to note the required image size during model development. A few images from the dataset are shown below. Note that the image size or quality does not bring down the accuracy of a model. A model trained on high quality images will need more computational resources.

Figure 3: Examples of images with 'Neutral', ‘Happy’, ‘Sad’, ‘Surprise’ labels respectively. (Retrieved from https://www.kaggle.com/datasets/msambare/fer2013)

3.5.1.3 Data Preprocessing

The data was next preprocessed to be prepared for the model that will be used for classification in this project, MobileNetV2. MobileNetV2 is an efficient convolutional neural network architecture used in various computer vision tasks such as image classification, object detection, and facial recognition. It is designed to maintain high accuracy while being lightweight and fast, making it suitable for applications and devices with limited computational resources. Processing the data correctly is critical as it ensures that the data is in a form that the model can efficiently process and learn from. MobileNetV2, like many deep learning models requires that the input data to be a certain size and format (224 by 224 for example).

The images were preprocessed using a utility class called ‘ImageDateGenerator’ in Keras TensorFlow. This data generator helps in loading and augmenting images for deep learning models. It serves both as a preprocessing tool and a tool to save computational resources. Using the data generator, we are able to apply random transformations to the data such as rotation, scaling, adjusting brightness, contrast and more ensuring the generalization of our model to be applicable in real world applications specifically in the context of engineering education. Generators are also useful for handling large datasets on computers with limited RAM. Thus, implementing these preprocessing steps, we not only prepare the data for our model and ensure generalization, but we also address potential memory issues and ensure computational efficiency. This approach ensures that our model training is both effective and feasible on most devices.

3.5.1.4 Model Development and Evaluation

MobileNetV2, a pre-trained neural network, was employed as the base model. It is known for its efficiency and compact architecture. The model was loaded with pretrained weights on the ImageNet dataset. This approach is known as transfer learning and leverages a model trained on a large dataset to improve the performance on smaller datasets. And although FER-2014 is not a small dataset, it is still advantageous to utilize ImageNet dataset as it contains over 14 million hand-annotated images. The model was configured to exclude its general top layers to accept the input we defined and preprocessed which is images with the shape of 224x224x3. We also set the layers of the base MobileNetV2 model to frozen to ensure that the learned features from the model are retained and not updated during our training step.

A global average pooling 2D layer was added after the base model. This helps reduce the number of parameters thus reducing the risk of overfitting or any computational load that might arise. Two additional layers were added with 128 and 64 units respectively were added both using a relu activation function. Lastly a output layer was added which is a dense layer with 7 units for each class and a softmax activation function. This layer outputs a probability distribution over the 7 emotion classes, allowing the model to classify the input images as one of the seven emotional classes. All three models were compiled using the adam optimizer and a sparse categorical cross entropy loss function since our classification problem is a multi-class task. To assess the model’s performance the accuracy metric was used. All models were trained over 25 epochs.

Furthermore, to ensure that our model's performance and accuracy is optimized the neural network was combined with a random forest model. Combining models in that manner is known as ensemble modeling. Combining models in an ensemble often leads to higher accuracy than any single model can achieve alone. For example, random forests are known to their robustness to noise in the data, while neural networks can be sensitive to it if not properly regularized. Thus by combining both, the ensemble can better handle noisy or variable data. Therefore, the general model architecture chosen for this study is an ensemble model with a neural network and a random forest.

3.5.1.5 Preliminary Model Evaluation

We are in the process of testing many different configurations of our model. Our current model that yielded the best accuracy out of previous configurations has an accuracy of 48.37% which is an improvement on our previous models and considered a good preliminary result in the area of image classification and emotion predictions. Additionally, through looking at other metrics we can study the model's performance in predicting certain classes. In terms of precision, which measures how many of the instances predicted as positive by the model were actually positive, classes 'fear', 'happy', and 'surprise' yield the highest precisions with 43%, 55% and 67% being the precision of each class respectively.

4 Preliminary Insights

4.1 Invention Design Process Step, Engineering Practices, and Expressions

A brief overview of the seven steps of the Invention process namely – problem identification and definition, understanding, ideating, designing, building, testing and communication were presented and explained to the families. This included a summary of the challenge and safety guidelines. The following child-adult facial expressions were included in the predictive model and observed through the grandmother-granddaughter invention process:

a) **Happy:** This was observed as both grandmother and daughter began brainstorming and sketching their design ideas, indicating great interest and that they find the design activity rewarding. The emotion showed positive engagement and excitement. Their discussion consisted of asking questions, demonstrations and trying to find answers. Each sharing and explaining their thought process. The observed engineering practices included creativity in problem solving, communication, and collaboration.

b) **Neutral** – The neutral expression was observed in the designing phase. The grandmother's gaze is focused on the daughter as she gestures, while looking attentively at the grandmother. The grandmother proceeds to explain the concept and provide feedback as they discuss an aspect of their design. The intense gaze and thoughtful design consideration during the ongoing discussions from both grandmother and daughter indicate active engagement in the design process. They continued to modify and label their sketches into more concrete design plans. Their actions suggest a collaborative effort in the design process, which is crucial in engineering design.

c) **Sad** – This emotion was observed in the building phase of the design activity. The building phase is characterized by hands-on activities from both participants. Although their faces indicated sadness, the interaction is constructive as they both decided to select another material relevant to each design component when the initial material chosen did not fit properly in the final product assembly. The grandmother directs the process and instructs the daughter on the next steps. They keep trying diverse ways to build the prototype until they arrive at a working solution. Active engagement and collaboration are observed as crucial aspect of their design process.

d) **Surprised –** This emotion was observed in the building and testing phase of the design activity when their design ideas did not meet the required constraints. They focused on assessing and satisfying the functionality and feasibility of their prototype. Required changes were made when things didn't work as expected. The conversations between both family members yielded new insights. The surprise emotion occurred due to the sudden change in the state of understanding or expectations of the project. This signifies moments of learning and adjustments beneficial to pivoting the design process in engineering design. Active engagement, collaboration, and communication were observed.

4.2 Observed Engineering Practices

a. **Collaboration and teamwork:** This is expected in family-oriented activities. The family showed clear understanding of the problem. The brainstorming, ideating, designing, building, and testing allowed for active engagement in the design activity by both parties. It created an environment that supports learning.

b. **Mentorship:** Throughout the design activity, the grandmother took on the guiding role, providing answers to questions that help the daughter in navigating the challenges of the design process. One of the questions include: "What else can we add to protect the egg (fragile object)?" The grandmother directed her to add more of the wool to act as a cushion to the interior part of their prototype.

c. **Emotions -** Both participants expressed emotions of being happy upon completing the design task within the specified time and when the testing was successful. The family were both engrossed in the design task. The grandmother was so proud of their final prototype, she took pictures of the daughter during the testing phase. She exhibited a huge sense of satisfaction from completing the design process and building a working prototype.

d. **Iteration and updated designs.** - the family first sought to build the base prototype which they continued improving to align with the testing criteria. Once this was completed, the daughter went on to improve the aesthetics of their prototype by adding colorful strips to the top exterior.

5 Discussion

Our findings showcase how families engage with STEM in informal spaces. It further highlights the different emotions observed as they engage in the design process, furthering our understanding of the role of family engagement in enhancing children's experiences and developmental outcomes in collaborative, hands-on activities. An understanding of these emotions will be helpful for instructors in reinforcing STEM identities in underrepresented groups. The occurrence of engineering practices such as collaboration, iteration, and questions provide insight into how engineering and design emerge in Black families engineering and inventive experiences. Additionally, evidence of engineering practices and along with an investigation of facial expressions occurring during the invention process can give insight into the significance of family members' roles as their children are STEM related skills and knowledge. Black families play a significant role in supporting students in developing self-identity, maintaining concentration and navigating the obstacles they face while pursuing their a career in STEM [28]. The supportive environment created through family-child interaction can not only enhance children's cognitive, social, and emotional growth but also provide rich and stimulating context for their STEM and engineering design learning experiences.

5.1 Implications for Practice and Further Research

These findings have implications for Black children's learning and development, emphasizing the positive impact of family engagement in hands-on activities. The preliminary insights gained from this analysis have practical implications for designing and facilitating design-build-test-communicate activities. Educators and practitioners can leverage the understanding of family dynamics to create more inclusive and effective learning environments for children and students as they matriculate to college STEM classroom.

6 Conclusion

The use of python to identify facial expressions during an invention process activity coupled with qualitative analysis of specific interactions during the invention process stand to contribute a rich and detailed portrayal of family-child interaction within the design-build-test-communicate activity of Black families. As this work continues, we hope to offer valuable insights for educators, researchers, and practitioners seeking to understand and promote effective family engagement in hands-on learning experiences. This work emphasizes the significance of family-child interactions within Black Families as they engage in engineering learning and exploration. There will be increased opportunities to empower Black students and improve their sense of belonging to STEM fields, as we better understand, document, and celebrate how Black families' engineering practices are enacted.

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