Threshold Crossings in Data Science and Cybersecurity Professional Development: A Six Week Research Experience for STEM High School Teachers

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Abstract:- **This paper explores the experiences of 11 high school STEM teachers learning cybersecurity concepts during a six-week summer Research Experience for Teachers (RET) program. We applied the threshold concept lens to make meaning of the troublesome knowledge that teachers found difficult and how they overcame those difficulties during the data science and cybersecurity professional development. Thresholds are core concepts considered troublesome in learning that, once understood, have a significant impact on the learner's mastery of a discipline. The threshold concept theory offers a potential lens on teachers' learning, focusing on concepts that are troublesome and transformative. The study involved 11 high school teachers—six men and five women—teaching mathematics, chemistry, and physics in grades 9-12. We used naturalistic observation to record teachers' behavior during their liminal and transformative stages. We found evidence that after the RET program the teachers' level of interest, perception, confidence, and motivation improved. This was an indicator of a quality transformation, a key concept in threshold crossing.**

***Keywords*:** **cybersecurity, data science, high school teachers, threshold concept.**

I. INTRODUCTION

Data democratization and the age of Big data has transformed the world together with the tools and skills that employees use to perform their functions (Markow, Braganza, Taska, Miller,& Hughes, 2017). The digital world sees massive daily data generation adding to the volume and variety of Big Data (Joglekar & Pise, 2016). There is a need for institutions to make insights from the voluminous data for competitive advantage (Provost & Fawcett, 2013). Consequently, data science prominence is growing in industries, academia, among other circles (Kross & Guo, 2019). Markow et al. (2017) opined that the demand for data scientists has put pressure on the supply of data science talent. PwC and Business-Higher Education Forum-BHEF (2017) reported that the use of data science skills can improve many sectors including cybersecurity. However, Asia-Pacific economies are unable to capitalize on data science and analytics due to a lack of skills and talents. Markow et al. (2017) project that by "2020 the number of positions for data and analytics talent in the United States will increase by 364,000 openings, to 2,720,000" (p. 3). There is thus a need to look beyond the data scientist to create talents for a variety of roles. Since data democratization affects different career paths, it is the onus of the academia to make data literacy a requirement for every student at high school to aspire a career in data engineering, data governance and lifecycle, data privacy and security specialists, among others (Markow et al., 2017).

Knowledge of data science and cybersecurity has recently become a crucial tool for life. In particular, the rise of the digital economy and online monetary transactions have exposed information computer technology (ICT) systems to cybercriminals (Opher, Chou, Onda, & Sounderrajan, 2016).The extended cyber surface is a lucrative opportunity for cybercriminals and is more expensive and difficult to secure (De Zan, 2019). Studies estimate the cost of cybercrime to have risen to$600 billion(0.8 percent) of the world global incomeup from $500 billion in 2014(Centre for Strategic and International Studies (CSIS) & McAfee, 2018; Lewis, 2018). As a result, cybercrime is now a feasible threat to anyone in society, and cybersecurity breaches are inevitable (Khari, Shrivastava, Gupta, and Gupta, 2017).With the continued growth of internet use, Goutam (2015) identified the vital need for internet users "to protect themselves from online fraud and identity theft" (p. 14) making cybersecurity a necessity for individuals, families, and education institutions, as well as public and private organisations.

However, the U.S. job market currently has a shortage of 2.93 million cybersecurity experts (De Zan, 2019).Cybercriminals, terrorists, and warmongers will dominate cyberspace if the cybersecurity skills shortage continues (Khari et al., 2017). The U.S. education system must train knowledgeable and skilled professionals to protect online data and networks from malicious cyberattacks (Rowe, Lunt, & Ekstrom, 2011). As De Zan (2019) observes, this will require policy interventions that will improve "the reactivity of the education and professional development systems through new degrees or courses, and [promote] more practical experience [of cybersecurity skill use] in class" (p. 18). Foroughi and Luksch (2018) noted the significant role that data science plays in cybersecurity as it allows "the utilization of the power of data (and big data), high-performance computing and data mining (and machine learning) to protect users against cybercrimes" (p. 3).Along with Authors (2019), we argue for the incorporation of data science and cybersecurity elements into the K-12 curricula to better prepare students for majors in these areas.

Oneway to increase the number of cybersecurity professionals in the workforce is to train more teachers and encourage them to integrate data science and cybersecurity concepts into their classrooms. Teachers play a major role in influencing learners' ideas of which career paths are attractive. Javidi and Sheybani (2019) found that teachers' fluency in computing skills was associated with a more positive perception of computing careers among the learners in their classrooms. The number of hours spent with learners in the K-12 program positions teachers as role models and authorities (Javidi & Sheybani, 2019). Thus, K-12 needs more teachers with positive attitudes toward data science and cybersecurity.

Like other educators, computer science educators face the question of how to make data science and cybersecurity concepts accessible to learners which are determined by the learning theories that educators adopt (Tucker, Weedman, Bruce & Edwards**,** 2014). Research indicates that in every discipline, some concepts pose difficulties for learners. Kallia and Santence (2017) refer to these concepts as thresholds whose "understanding is significant to master a discipline" (p. 4). The threshold concept approach can provide a useful lens in examining teachers' transformation in a learning journey (Yeomans, Zschaler, & Coate, 2018) toward data science and cybersecurity professional development.

Although substantial research has addressed the use of threshold concepts in teaching computer science, most studies focus on the undergraduate level and address the threshold concept from a broader perspective (Sanders &McCartney, 2016; Yeomans et al., 2018; Zwaneveld, Perrenet, & Bloo, 2016). We are unaware of any studies that have applied the threshold concept lens in understanding how learning takes place in data science and cybersecurity professional development for K-12 STEM teachers. Our study used naturalistic observation and content analysis of teacher products in seeking to identify threshold concepts based on teacher behavior during the data science and cybersecurity professional development sessions.

Theoretical Approaches to Learning in Cybersecurity

This study was designed to identify the key concepts that were troublesome to the teachers during the cybersecurity professional development process and how the teachers achieved transformation. The resultant findings could help educators improve professional development programs in data science and cybersecurity. Thus, a focus on the troublesome and transformative concepts of threshold concept theory was appropriate for this study. In the following section, we briefly discuss the components of the threshold concept theory and its application in teacher professional development.

II. LITERATURE REVIEW

A. Characteristics of Threshold Concepts

Meyer and Land's (2003, 2005, 2006) threshold concept theory posits that threshold concepts are key portals educators must unlock for students to reach new and previously inaccessible knowledge. In education, the threshold concept lens has been used to identify key concepts that determine learners' mastery of a subject area (Barradell, 2013; Sanders & McCartney 2016; Yeomans, Zschaler, & Coate, 2018).Sanders and McCartney (2016) noted several characteristics of threshold concepts. First, those threshold concept sare transformative: they cause a shift in perception and identity. Second, threshold concepts are integrative ,in that they expose something previously hidden, such as a connection or mode of understanding. Third, such concepts are difficult to reverse: once learned, they are unlikely to be forgotten or unlearned. Fourth, threshold concepts are potentially troublesome because they are initially counter-intuitive or uncomfortable. Finally, threshold concepts are bounded, in that broader frameworks of knowledge restrict the conceptual spaces. The learner's transformation is grounded in the prior knowledge possessed before learning a new concept. After learning a new concept, the learner is unlikely to revert to the old way of viewing things and is considered to have crossed the threshold. Further, the learner integrates the new knowledge to perceive the relationship of concepts in the discipline. Nevertheless, knowledge is bounded to a certain discipline, and learning a concept might become trouble some(challenging to grasp and understand) to learners (Barradell, 2013).

Yeomans et al. (2018) used 12 undergraduate students and five professional software developers in a college in London, United Kingdom, to explore concepts considered challenging in computer programming. They intended to "improve the learning experience for students" (p.7). The findings established that students considered some concepts to be troublesome and transformative. For example, while all student participants identified "class and inheritance", a direct threshold concept, third-year students' participants considered "user interface architecture" to be a gateway concept. That is, the idea of "user interface architecture" connected them to the application of programming to real-world contexts rather than connecting them to solving an exercise in the classroom" (Yeomans et al., 2018, p. 11).

The threshold concept framework, therefore, deepens our understanding of participants' critical learning experience (Tucker, Weedman, Bruce & Edwards, 2104). Thus, applying the framework to teachers reveals that they go through an abstract gateway involving moments of reconstruction(Meyer &Land 2005) in their data science and cybersecurity professional development lessons. Barradell (2013) found the threshold concepts framework suitable for teaching and learning since it "provides an opportunity reflect on what is taught, why it is taught, how and when it is taught" (p. 268).

B. Conceptual Threshold Crossings

In a learning environment, the threshold concept presents ideas that aid teacher and student learning (Barradell, 2013). However, Eckerdal et al. (2006) argue that many learners get stuck in these ideas because they are “conceptually difficult and lead to a broader and necessary understanding of the discipline” (p. 104). They thus enter a liminal state of confusion between the new and the old understandings (Meyer & Land, 2005; Sanders & McCartney, 2016). One way to enable learners to move forward is by making them aware of and helping them understand the importance of the threshold crossing moment (Kiley 2009;Wisker, 2010). When learners endurea liminal learning experience, as Tucker et al.(2014) note, they are transformed and acquire a new identity that enables them to integrate and recall concepts in the discipline in a new, but informed way. Consequently, crossing a threshold concept is likely to create change in the learners’ intellect and thus, affect the way they speak about the discipline (Wisker, Kiley & Masika, 2016) so that the quality of transformation becomes essential to a threshold concept.

C. Teachers' Experiences on Overcoming Threshold Concepts

Park (2015) used threshold concepts in a study of the professional development of 20 high school chemistry teachers. Results indicated that teachers overcome thresholds both while learning and teaching, as they had a unique way of overcoming threshold experiences. The study revealed an association between the uniqueness of the relationship between the teachers’ mastery of subject matter knowledge (SMK) and pedagogical content knowledge (PCK) and how they overcame the threshold concept challenges. Park (2015) further established when teachers overcome troublesome concepts they experienced “a transformed way of thinking” (p. 311). Teachers in this study went through the process of reflection and reconstruction to experience transformation. Those teachers who overcame the troublesome status were able to change their teaching of chemistry, due to improvement in their efficacy and confidence in teaching different concepts. Park (2015) believed that the “a-ha” experiences improved the “teachers’ positive attitude towards science teaching and learning, teacher efficacy, and interest in science” (p.317).

Although Javid and Sheybani (2019) did not apply terms associated with threshold concepts in their study, but the teachers they studied experienced transformation and were able to acquire a new identity after professional development. This study engaged 30 high school teachers in a one-week summer pilot study on cybersecurity awareness. The professional development aimed at empowering teachers to “bring cybersecurity projects, technology, and curriculum into their classrooms, and creating awareness among the teachers on the significance of cybersecurity” (p.8). The study found that the teachers’ level of interest, perception, confidence, and motivation improved after the professional development. Most teachers (27 out of 30) reported preparedness to teach basic cybersecurity concepts.

Research has shown (Javid and Sheybani, 2019; Park, 2015) that once the teachers become familiar and comfortable with the troublesome concepts, they acquire the identity of an expert in the discipline. Educators should recognize the strong emotional responses associated with the teachers’ or learners’ experience with liminal spaces since they are an indicator of a potential threshold concept (Yeomans et al., 2018). We, therefore, advance the argument that there is much that can be achieved if data science and cybersecurity professional development are viewed through the threshold concept lens (Eckerdal et al., 2006).

D. Theoretical Framework

This study used a theoretical framework that focused on the five characteristics of the threshold concept: troublesome, irreversible, integrative, bounded, and transformative knowledge (Meyer & Land, 2003, 2005,2010). Tucker et al. (2014) identified transformation as a key prerequisite in a threshold learning experience and advanced the notion that the dimension of difficulty informs educators in identifying ambiguous concepts concerning the learner’s liminal stage (Eckerdal et al., 2006). Consequently, we opted to give more weight to transformation and troublesome traits in discussing the threshold concept in this study. We looked for the evidence of the emotional state of teachers, an indicator that the teachers were stuck, as well as the evidence of critical threshold crossings, an indicator of the teachers’ quality transformation.

1. *The Current Study:* This study aimed to explore how high school STEM teachers experienced the learning of data science and cybersecurity concepts using the threshold concepts framework. Understanding the teachers’ critical learning portals would inform the educators on how to redesign the data science and cybersecurity curriculum and its integration in the K-12 classroom. Data science and cybersecurity education programming in K-12 is meant to provide learners with valuable learning experiences. The RET program was thus meant to provide data science and cybersecurity professional development to 11 high school teachers in a six-week program during Summer 2018. The summer professional development was ideal for the researchers “to study the existence of threshold concepts and add to our understanding of how they contribute to expertise” (Tucker et al., 2014, p.157) and explore how the implications may inform curriculum development. For this paper, we have used a threshold concept lens

to address the teachers' critical learning experiences in data science and cybersecurity.

III. METHODOLOGY

The study took place during a six-week Research Experience for Teachers' (RET) professional development at a large University in Western Texas during the summer of 2018. The study's main objective was to explore the learning experiences of K-12 STEM teachers to inform educators on how to improve the RET cybersecurity professional development program. In the following subsections, we discuss the setting of the study, the selection of participants, data collection, and analysis.

1) Study Setting: RET is a National Science Foundation-funded project with a fundamental goal of introducing high school STEM teachers to data science and its application in cybersecurity concepts and how to integrate those concepts into their respective curriculum (Maina et al.,2019). The participants were 11 high school teachers (five women and six men). The facilitators of the professional development program were three computer science professors and three education professors. The professors were assisted by three graduate students from computer science and three from the college of education. The computer science professors were involved in teaching and demonstrating the data science and cybersecurity concepts to the teacher participants. Computer science graduate students assisted the teachers in practicing the concepts they learned during their interaction with the computer professors. The professors of education were responsible for guiding the participants to integrate the new data science and cybersecurity concepts into their K-12 curriculum. Graduate students from the college of education assisted with data collection.

For 6 weeks, the teachers participated in three sessions per day,5 days a week. They spent 3 hours (9am - 12pm) everyday learning data science and cybersecurity concepts. In the afternoon, the teachers interacted for one hour with the computer science graduate students (1 pm - 2 pm) in a practice and application session, and another hour (3pm - 4pm) with education faculty to discuss ways to integrate the concepts learned into their curriculum. Friday afternoons were set aside for education faculty to work with the teachers on unit and lesson planning, as well as collaborative research projects.

2)Teacher Participants: The educators in this study all teach STEM subjects in 9-12th grade at schools in the West Texas region and were recruited through a rigorous application process. The recruiters considered the applicants' leadership skills, STEM background, ability to integrate the new data science and cybersecurity skills in their teaching subjects, and collegiality with their peers, as documented in an essay they submitted as part of the application process. The recruitment process encouraged teachers to apply in cohorts and targeted Title 1 schools, where 40% or more of the student body have low socioeconomic status according to federal government designation. Those recruited to the project were assigned to teams based on their subject areas: chemistry (4), physics (3), and mathematics (4).

3) Data Sources: We collected data using naturalistic observation and content analysis of teacher products (collaborative group research projects, PowerPoint presentations of research projects, and unit and lesson plans). The rationale was to capture a sense of which concepts were challenging at the beginning and to identify any behavioral changes by the teachers as they experienced the challenges. We, therefore, exercised minimal direct interaction with the participants and recorded the observations on the teacher's natural classroom interaction with their instructors. It was easy for the researchers to observe the participants' emotional state during professional development activities. In line with Meyer and Land's (2005) advocacy for methods of observation and inquiry that allow researchers to explore the different ways learners experience threshold concepts, we conducted naturalistic observations every day for the 6 weeks that the project was in session. We shared our daily observations through a dropbox and met every Friday afternoon to discuss our observations. In total, we observed the teachers for 20 hours a week for 6 weeks.

We focused on behaviors related to the difficulties participants faced and their emotional responses, which are characteristics of liminal space. This was in line with Cousin's (2006, 2009) advocacy for observation and inquiry of the emotional state that learners exhibit during liminal experiences that make learning troublesome. Cousin (2009) argued that the liminal state is a metaphor and illuminates the conceptual transformation that learners undergo, and the difficulties and anxiety associated with the transformation. We kept track of what was happening in the classroom, including the time the computer science faculty and graduate students spent delivering the content and material.

We coded and analyzed the collected data to establish evidence of anxiety, which indicates that "a troublesome threshold in learning is being or has been crossed" (Tucker et al., 2014, p. 155).Following an intensive analysis, and guided by the five characteristics of threshold concepts, there was evidence of threshold crossing. The emerging themes were information extraction and knowledge discovery (programming, abstraction, and coding concepts), integration (integrating data science in cybersecurity), and language and viva prowess (oral presentation of the final project). The themes are discussed in the following sections, reflecting evidence of the liminal stage and the critical threshold stages crossed.

IV. FINDINGS

A. Evidencing Critical Liminality

Confusion and Mimicry: Information extraction and knowledge discovery were both troublesome and transformative to the participants, all of whom are referenced below using pseudonyms. Learning data science and cybersecurity concepts was a requirement for the participants and thus, their passion and vision were significant in understanding the concepts. For instance, data mining entailed examining how participants predict a problem, classify, and understand clusters of information, and identify how the clusters were associated with each other. The participants also engaged in learning how to use R-Programming to effectively conduct data mining. The programming language demanded the teachers go through lessons on coding and abstraction. Although it emerged that the teachers were passionate about learning the key concepts in data science to enable them to comprehend cybersecurity concepts, the concepts posed an obstacle to learning. For example, during the first day of professional development, one observer noted that teachers were stuck answering a question on differentiating between cybersecurity and computer security. The observers wrote:

All the teachers were quiet, only one teacher tried to answer. The other teachers are focused on the power points (sic) slides. Probably looking for a hint? (Observer 1)

Their distant facial expressions can tell they are not following. They looked not sure of what they are supposed to do. A teacher sitting at the back looks a bit distant. (Observer 2 & 3)

We made a similar observation on the following day when the teachers were working in their groups. The math group members were puzzled and anxious. We noted:

The three members [of the math group] seem to be having a challenging problem. It is unusual for them to work individually. In a short while, an instructor arrives and [Brian (not his real name)] seeks clarification from the instructor on a topic she had taken them through on cybersecurity. One teacher is still discussing with the instructor. He puts [on] a distant face and keeps responding with, inaudible utterances.

A question posed to the instructor further communicated the troublesomeness of the concept. The notes indicate:

All this moment [Brian] expresses a discontented mood on his face. He keeps on rubbing his hair. He is now using phrases beginning with, "if…"(Observer 3)

At this point another observer noted:

Not sure whether the explanation is going down well with [Brian]. At different intervals, [Brian] poses questions starting with*"so…" to confirm the explanation*. (Observer 2).

At the close of the session we observed:

The math group appears a bit uncomfortable with their project. There is little coordination [between them].

Another member of the math group, Leah (not her real name) confirmed this impression. After the instructors informed the math groups that they were expected to present their project as a group, Leah said, "We have not been working together and we may not be on the same page."

To overcome confusion and mimicry, the study participants posed questions to the instructors and discussed the challenging concepts among themselves. They also pointed out areas they felt comfortable with and identified areas they needed instructors to revisit. We recorded several instances where teachers posed questions and engaged in discussions. For example, in the second week when the instructors introduced a lesson on 'Data transformation and types of data attribute concepts', there were elements of partial understanding which led to participants raising questions and engaging their instructors and other participants in discussions. We observed:

It took teachers some time to retrieve the data and plot graphs but those who finished earlier assisted their colleagues—collaboration was exercised. The instructor was alerted of a teacher who had difficulties with the data on her computer and she came to her aid. One teacher engages the instructor by posing questions on data transformation. (Observer 1)

We considered this stage a partial understanding since teachers could show minimal signs of new knowledge. The participants had not yet crossed the threshold concept, as evidenced in the following observation. It emerged that they were relying on mimicking R- programming language through copying and pasting the R syntax (code) to plot their graphs.

Notable was that interaction only revolved around three teachers while the other eight followed silently. As the class progressed [those eight] teachers appeared withdrawn since the instructor did not engage them in her monologue. (Observer 1)

It was not long before the participants exhibited signs of knowledge of their liminal stage, a sign of imminent transformation. After the teachers were introduced to a lesson on 'Artificial Neural Networks' (ANNs), it emerged that although the concept was more challenging than the previous ones, teachers were able to relate with real-life examples. The instructors also used the whiteboard to illustrate the concepts using real-life examples. For example:

They were able to relate the ANN concepts to [a] decision tree topic that they were taught in the previous lesson. Teachers were excited, and the data presented seems to relate to topics that they had experienced in their lives. (Observer 1)

The group members are free and candid with the instructor on the challenges they are facing in interpreting their data. The instructor and the teachers interact using the whiteboard to discuss the concept of simple matching and the Jaccard coefficient. The three teachers simultaneously engage the instructor with more questions on 'similarity.' (Observer 2)

Through regular feedback from instructors, the participants were able to comprehend the concepts related to data science, paving the way for a transformation in the next stage, which required them to integrate the new knowledge in developing a research project.

B. Evidencing Transformation

Integrative-The research projects: The participants were expected to use the new knowledge acquired to design research projects that would help address a cybersecurity threat. The ability of the three groups to integrate the new knowledge was mainly exhibited through collaboration. We observed how each member of the groups - mathematics, chemistry, and physics - contributed to the development of the cybersecurity project. We found strong evidence of collaboration among the members of the three groups as demonstrated in the design and presentation of their projects. For example, the chemistry group collaborated and developed a project on how URL attributes could be used to help identify phishing sites. The group also outlined six features that could help in detecting a phishing URL. The physics group developed a project on intrusion detection. The objective was to examine how data could be used to detect cyberattacks. The math group developed a project on spam or not spam. The objective of their project was to examine the use of computer models to distinguish spam text messages from legitimate text messages. In their reflections, they mentioned that they had acquired "a deep understanding of K-Nearest Neighbor (KNN) classification for building a model ourselves." They also noted that "text mining created interesting challenges for analysis for us to explore." Gaining knowledge and integrating it had the five characteristics of threshold concepts: troublesome, integrative, irreversible, and transformative effect on the participants.

C. Irreversible knowledge

Language transformation: We considered the third threshold concept, language, and viva prowess, as the overall measure of the participants' transformation. Wisker, Kiley, and Masika (2017) identified language as a core concept to "presentation in both its semiotic and syntactic form" (p.121)and indicated that learners should be engaged in active metacognition related to the language skills. The choice of vocabularies and expression of ideas is an indicator of the participants' quality of understanding of the cybersecurity concepts. The groups were able to express themselves using technical terms. For example, during the project's oral presentation, the chemistry group gave an outline of the procedure they would follow in implementing their project using the following terms:"data loading, descriptive analysis, data cleaning, data visualization, model building, prediction, and evaluation, then concluding and having a comparison." Language use, therefore, reflects the conceptual threshold crossing through the expected expression and communication within the use of discipline and community of practice. Thus, the ability of the three groups to present their projects using data science and cybersecurity terminologies is an indicator of the irreversible conceptual transformation they experienced. Consequently, we found the language and viva prowess threshold concept to be irreversible, transformative, and bounded for the teachers during professional development.

V. DISCUSSION

A. Significance and Limitations of the Study

The main goal of this study was to show conceptual threshold crossings during the six-week-summer cybersecurity professional development involving 11 high school teachers. Wiskeret al.(2017) emphasized the importance of evidencing intellectual, cognitive achievement, and epistemological awareness as indicators of conceptual threshold crossings and learning of cybersecurity. Knowledge in data science, integration, and viva prowess produced interesting findings within data science and cybersecurity education in this study. The study findings have added to the existing literature on the thresholds within computer security literacy and specifically, on high school STEM teachers' transformative journey in learning cybersecurity concepts. The study identified the different learning portals that teachers unlocked to become experts in the cybersecurity domain. Computer science professionals and faculty could be informed by this study about how abstract language in computer science hindered the participants' learning of cybersecurity. Further, the findings on how the teachers were able to integrate the new knowledge after acquiring the language of cybersecurity can inform the instructors on how to improve cybersecurity teaching methods.

However, we recognize that some limitations might have influenced our findings. Our participants were selected through convenience sampling, where one criterion for the participants' selection was availability for professional development during summer. The sampling method and sample size, according to Etikan, Musa, and Alkassim (2015), affect the researchers' "inductive inference concerning the population of interest" (p. 2). However, since the study was focused on observing the participants' change of learning behavior, our sample was narrowed down to the 11 participants. Time was another limiting factor: six weeks was a short time for educators to teach all the concepts associated with data science and cybersecurity. We observed that the amount of teaching load was overwhelming for the instructors and the participants and could have affected the learning trajectory of the teachers. For example, we observed:

The outstanding factor in this session was the overwhelming materials that the instructor was to deliver within two hours. In the process, she ended up in an uninterrupted monologue while the teachers were busy on their laptops. (Observer 3)

Despite these limitations, we believe that our study provides valuable insights into the teaching and learning of data science and cybersecurity to high school STEM teachers.

B. Implications for Pedagogy and Threshold Concept Research

We understood that liminality is a transient phase, an indicator that a learner has not successfully acquired knowledge of a certain discipline. Meyer and Land (2005) likened liminality to a metaphor that informs educators of the learning trajectory of a learner. As a result, by applying a conceptual threshold framework to explore the learning process of cybersecurity in this study, we advance the argument that educators' understanding of the troublesome concepts is vital in designing and implementing their professional development modules and curriculum. Thus, knowledge of a learner's liminal experience in this study is a guide to educators in identifying the epistemological obstacles and thus, developing strategies (Wisker et al, 2017) that can transform the learners through data science and cybersecurity professional development. To evidence conceptual thresholds, we looked at the possible causes of tensions in the learning process during the liminal stage and the teachers' transcendence. We observed that some major barriers to learning the concepts were associated with the instructors' use of unfamiliar computer science terminologies that invoked the teachers'struggles. The teachers might have found the vocabularies troublesome and misunderstood the concepts,making them feel inadequate. The troublesomeness may also have contributed to the teachers' failure to articulate conceptualized questions at the beginning of the professional development sessions. Teachers admitted that they lacked computer security literacy. Only one out of the 11 teachers had a background in computer science andeven she had little knowledge of cybersecurity and data science terminologies.

It was evident that the instructors and the teachers later initiated strategies that included doing collaborative group work, demonstrating initiative, asking questions, and applying metacognition that led to their transformation. The new knowledge was manifest in the discussions the teachers had during their collaborative activities as they designed their group cybersecurity projects. The command of cybersecurity and data science language was evident. Further, the teachers exhibited computer security literacy during the oral presentation of their group projects. The liminal stage that the teachers experienced during their first week of professional development helped them change their attitude towards cybersecurity and the transformation changed their identity (Eckerdal et al., 2006). The change of identity indicated that teachers' subject matter knowledge is a component that helps them overcome the concept threshold in their learning (Park, 2015).Such changes in learners' use of a language of the cybersecurity discipline. Yeomans et al (2018) observed that when teachers master concepts that make them feel like programmers, the emotional transformation indicates the teachers feel like experts in cybersecurity.

Therefore, we concluded that the use of threshold concept theory in high school STEM teachers' cybersecurity instruction enabled us to identify the learning portals that teachers needed to enter during professional development. Equally, the threshold concept framework allowed us to critically analyze and make meaning of the observation data we collected. The findings from the analyses are a key guide for designing ways to teach cybersecurity concepts to educators.It also emerged that the application of the threshold concept theoretical framework informed the researchers of key concepts associated with computer security literacy, which can be explored further using the same theory to study other groups of teachers and students.

VI. CONCLUSION

As the number of cybersecurity learners rises, it is necessary to have frameworks that inform both the data science and cybersecurity curriculum developers and instructors to address concerns about the quality of learners' transformation. The threshold concept lens is one ideal way of looking at transformed learning needed for a high school teacher intended to promote cybersecurity topics in school. This study has added to existing knowledge on threshold concepts in cybersecurity and expanded literature in computer security literacy. The study presented the characteristics of threshold concepts theory and its application in cybersecurity professional development with high school teachers. The study presented three themes that related to the core data science and cybersecurity learning portals that teachers transcended to become experts. Consequently, the study provided evidence that data science and cybersecurity concepts were troublesome to teachers, while mastery of the subject matter was crucial to teachers in overcoming the liminal stage. There was also evidence that to unlock the learning portals, instructors and teachers devised new strategies to demystify terminologies that made teachers get stuck. Our findings, therefore, inform computer science pedagogy and curriculum stakeholders about the importance of identifying concepts in the curriculum or teaching modules that might require additional support for learners. We have also added to the wider debate on the applicability of the threshold concept approach to data science and cybersecurity education. The challenges we experienced in identifying core thresholds that characterize troublesomeness and transformation can offer insights to researchers and scholars interested in cybersecurity and help them to explore further whether the concepts are sufficient to improve pedagogical approaches.

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