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Using Bayesian Networks to Provide Educational Implications: Mobile Learning and Ethnomathematics to Improve Sustainability in Mathematics Education

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Abstract: There are many Western apps that help students strengthen their mathematics skills through learning and game apps. A research project was designed to create an IOS Math App to provide Grade 6 Emirati students with the opportunity to explore mathematics, then, using Bayesian Networks, to examine the educational implications. The learning app was developed using ethnomathematics modules based on the Emirati culture. Students were required to navigate through several modules to examine various mathematical concepts in algebra and geometry. The survey was written for Grade 6 English language learners. Based on the Bayesian Networks, the findings suggested that if students are allowed to explore mathematics based on familiar cultural norms and practices, students with grades A and C would get higher grades. However, if students are not allowed to explore mathematics in line with their local culture, more students would receive an F grade, while some students with an A grade would get lower grades. Additionally, the findings showed that incorporating cultural elements had a positive change in students' liking and learning mathematics, even without a mobile device. However, not allowing a mobile device and not allowing culture had an increased negative impact on students' liking and learning mathematics. The last finding suggested that students valued ethnomathematics examples over a mobile device to learn mathematics. The research findings could help to improve sustainability in mathematics education by promoting ethnomathematics and mobile learning.

Keywords: Bayesian networks; ethnomathematics; mobile learning; UAE

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1. Introduction

Over the past decade, the United Arab Emirates (UAE) has embarked on an educational journey to revolutionize education [1–5]. The UAE government provided a mobile device to every Grade 6 Emirati student and educators who teach Emiratis with MAC laptops and AppleTVs. The innovative mobile learning initiative was an idea that would transform PreK–6 education. Additionally, the government provided funding opportunities for higher education institutions to offer professional development to PreK–16 educators. In order to maintain this innovative enthusiasm and momentum in education, a research study was designed to utilize two paradigms—ethnomathematics and mobile learning—to offer Grade 6 Emirati students an opportunity to explore mathematics using modules based on the Emirati culture.

1.1. Sustainable Development in Education

To improve the sustainable development in education around the world, the United Nations Department of Economic and Social Affairs Sustainable Development introduced

17 Sustainable Development Goals (SDGs) associated with 169 targets. Researchers and policymakers have made these goals a priority for today's children. Efforts to apply elements of sustainability goals in mathematics education is a fairly new phenomenon, though it is gaining momentum to meet the needs of the 21st century student. For instance, researchers have utilized the benefits of sustainability goals in student mathematical achievement [6–8], while others have explored the notion of sustainability goals to prepare future mathematics teachers in teacher education programs [9–11]. Some have even implemented sustainability goals to further the benefits on STEM education [12–14]. Still more work is needed to explore sustainability goals in the Gulf Cooperation Council (GCC) and Middle East and North Africa (MENA) region.

1.2. What Is Ethnomathematics?

Ethnomathematics is broadly defined as the study of the relationship between culture and mathematics. It is used to describe the ways in which mathematics is practiced among similar and dissimilar cultural groups. [15] defines the term "ethno" as the elements that make up a group's cultural identity (i.e., race, language, vocabulary, values, beliefs, norms, physical traits, symbols, etc.). Mathematics, in this context, refers to different aspects of thought and culture that lead to different mathematical structures, opinions, understandings, and explanations within concepts such as counting, measurement, sorting, organization, deduction, and modeling [15,16]. D'Ambrosio [17] defines ethnomathematics more definitively as "a program in history and epistemology with an intrinsic pedagogical action that responds to a broader conception of mathematics, while considering the cultural differences that have determined the cultural evolution of human mankind and the political dimensions of mathematics" (p. 133). Thus, the concept is considered an approach to teaching mathematics by researching and appreciating all societal histories, philosophies, and cultures [18]. The general theory of ethnomathematics draws attention to the fact that mathematics is fundamentally a cultural product, where each culture and subculture develops its own mathematics useful for them [19].

1.3. Ethnomathematics in School

Historically, mathematics, more than any other subject, has been perceived as being culture-free. It was noted that some mathematics teachers believe that, when teaching mathematics, they do not have to take the diversity of their students into consideration [20]. Such an approach not only disregards students' cultural knowledge as a critical component in empowering them intellectually, emotionally, and politically, but it also discounts historically significant mathematical advances produced from attempts to solve cultural and specific social problems. This includes such topics as geometry in Ancient Egypt, astronomy in the Middle Ages, and computing in the modern era ([21], p. 139). Mathematics educators have an obligation to assist students to discover and understand the power mathematics plays in their lives [21].

In the past, various approaches for diversifying mathematics education have proven to be effective. One approach, the Critical Race Theory, has shown to improve the achievements of minority mathematics learners [22]. Culturally responsive mathematics teaching enables students to relate mathematics content to their culture and communities [23–25]. Adam et al. [26] explained how a culturally relevant mathematics curriculum based on ethnomathematical perspectives and that holistically infuses the students' cultural backgrounds into their learning environment improved student agency. A previous study has revealed that students who receive mathematics instruction using an ethnomathematical approach excel in mathematics assessments [27].

D'Ambrosio [18] reported on teachers who differentiate between two types of mathematics: formal academic mathematics taught in schools (also known as school mathematics) and ethnomathematics practiced by diverse cultural groups. In this context, ethnomathematics researchers suggest that mathematical experience outside of school should also be addressed as authentic and appropriate knowledge for the classroom [28,29] Ethnomathematics research in schools has reported mixed results when students engage in traditional mathematics taught in schools and ethnomathematics. Baba [30] observed that children who were successful in making calculations in the streets were unable to solve similar problems on a school mathematics test. However, Karssenberg's [31] work showed that students were able to learn geometry, symmetry, and mathematical approaches in the context of cultural and historical geometry linked to Persian medieval architecture within Islamic culture.

Many scholars have discussed the benefits of infusing ethnomathematics into the traditional mathematics taught and learned in schools. Rowlands and Carson [32] argue that by engaging students in ethnomathematics, we create more opportunities for inclusive mathematical conversations and ensure that learners from indigenous and traditional cultures can bring important resources, ideas, and perspectives to these conversations. Additionally, they add that, "Ethnomathematics engages the teacher in a side of the mathematical conversation that opens up a route of access to the child's own unique modes of thought, both personal and cultural" ([32] p. 336). D'Ambrosio [33] explains that ethnomathematics allows us to witness and appreciate how mathematics continues to be culturally adapted and used around the world and through time.

D'Ambrosio and Rosa [34] identify two "main reasons" for bringing ethnomathematics practices into schools: to demystify school mathematics as a final, permanent, absolute, unique form of knowledge; and to illustrate the intellectual achievement of various civilizations, cultures, peoples, professions, and genders. Ethnomathematics practices inspire respect, solidarity, and cooperation between cultures and promotes a society free from arrogance, discrimination, inequality, and hatred [34].

Recent studies in ethnomathematics suggest that ethnomathematics support student agency, achievement, and creativity. Mursalin and Supriadi [35] explored Sundanese fifth graders' ability to develop creative mathematical designs. The findings report that the fifth graders were able to create dynamic creative mathematical designs that support the children's understanding of various algebra and geometry topics. Likewise, Prahmana and Istiandaru [4] examined the use of the Indonesia Javanese shadow puppet to explore the mathematical topic of set theory. The findings suggest that the Indonesia Javanese shadow puppet was used to convey many concepts of set theory, such as "definition of sets, universal sets, subsets, union of the set, intersection of the set, complement of the set, empty set" (p. 14). However, more research exploring ethnomathematics is desired.

1.4. M-Learning

Mobile learning (M-learning) has had a significant impact on education worldwide [36]. Research on the use of M-learning in education emerged in early 2000 [37,38]. Early research set out to design a theory of educational and lifelong learning mediated by mobile technologies such as handheld devices [39]. Since then, numerous articles focusing on M-learning have been published reporting on the increased educational use, advantages, and challenges of M-learning in education [38].

1.5. Educational Uses

M-learning has been successfully employed in various ways. For instance, Alzaza and Yaakub [40], discussed M-learning in terms of the next generation of E-learning. Other researchers have referenced M-learning as learning performed with the utilization of handheld, portable devices, such as smartphones and tablets [41–43]. Lam and Duan [44], discussed the anytime-anywhere convenience of student learning through mobile technologies. Fabian, Topping, and Barron [45], discussed the effect of mobile learning on primary student's mathematical attitudes and achievement. In general, research on M-learning discusses various opportunities for learners to access educational content anytime and anywhere in order to learn, increase knowledge retention, collaborate, share, and gather newly acquired knowledge.

Recent studies in M-learning continue to report on the increased impact of mobile devices [46]. Papadakis, Kalogiannakis, and Zaranis [47] conducted a study to examine the impact of computers and laptops on early childhood children's understanding of numbers. The findings reported that children who used personal computers and laptops outperformed the children who used no technology. However, the children who used laptops outperformed both the children who used personal computers and those who used no technology. Another study explored the effect of mobile learning on student comprehension. Wang, Kao, and Wang [48] reported on a study that investigated second graders' comprehension of multiplication. The research suggested that the children who used a mobile device experienced increased comprehension and achievement versus those children who were taught traditionally. Both studies support the notion that M-learning yields greater gains in student achievement. Yet, more research exploring the usefulness, challenges, limitations, and/or impact of M-learning and ethnomathematics is needed in the GCC and MENA region, mainly in the UAE. Due to the limited research on ethnomathematics and M-learning, the present research study aims to contribute to the research literature in the application of the ethnomathematical perspective, which encompasses contextualized practice in this geographical location.

1.6. Research Question

In light of these considerations, we decided to develop and build an IOS (Mobile Operating System) App that would integrate both high standards for mobile learning and ethnomathematics modules based on the Emirati culture. The intent for our app was twofold: (1) to provide Grade 6 Emirati students with opportunities to explore mathematics through a lens of the Emirati culture; (2) to encourage Grade 6 Emirati students to pursue STEM as a future career. The research question for the current study was, "What are the implications for Arabic speaking Grade 6 Emirati students who explore mathematics using ethnomathematics and mobile learning?"

2. Method

In this section, we present a pilot study to explore the Math App and survey. Next, the study participants and setting will be explored in detail. Subsequently, a discussion of the data—survey, data collection, and data analysis—will be presented.

2.1. Pilot Study

Before data collection for the research study, the research team sought to pilot the Math App and conduct a survey with one class of Grade 6 students (n = 24) in Al Ain. The Grade 6 students for the pilot study were English language learners, and we wanted to confirm the survey language was familiar to the students. Additionally, we intended to allow the students to have an experience with the Math App, which would inform the research team how students interact with the technology and the modules. In other words, were students able to navigate freely through the modules? Were students able to make sense of the Emirati modules? Both questions were responded to "affirmatively". No students provided any additional information that would require the research team to modify the Math App.

Pilot Survey. The Grade 6 students in the pilot study provided the team with valuable information for the survey. Two changes to the initial survey were made. Question 2 of the survey asked, "What is your current grade in mathematics?" Students in the pilot study had questions regarding the words *grade* and *mathematics*. This question was changed to "What is your current mark in math?" This change was based on students' recommendation. The second survey modification was with Question 9. The original wording was, "Before solving these math problems, had you solved math problems that relate to the UAE culture?" As the word "relate" needed to be explained to many of the students, the question was later reworded to read, "Before solving these math problems, have you solved math problems that connect to the UAE culture?" When the survey was administered for the research study, no students needed clarification on either question. Modifications to the survey were minor and did not change the content of the survey.

2.2. Participants

The students in the research study were Grade 6 students (n = 160) in the UAE cities of Al Ain and Abu Dhabi; similar to students in the pilot study, they were English language learners. Since government schools (Grades 6–12) are gender-segregated, the research team sought various girls' and boys' schools. The students in Al Ain were girls, and in Abu Dhabi, the students participating in the study were boys. The mathematical ability of the students was not significant for the study. The research team did not select the Grade 6 Emirati students who participated in the study. However, the team was responsible for suggesting that Grade 6 Emirati students be selected for the research study. Each school principal selected the class of Grade 6 Emirati students for the study. The major objective was to offer Grade 6 Emirati students an opportunity to explore mathematics based on the Emirati culture and provide implications for learning.

2.3. Setting

The research team visited various schools three times altogether. These schools were identified by the Abu Dhabi Department of Education and Knowledge (ADEK) and the United Arab Emirates Ministry of Education (MoE). During visit one, the Grade 6 mathematics teachers (n = 6), selected by the principal, were introduced to ethnomathematics. Again, the research team was not involved in the selection of teachers. This introduction consisted of allowing the teachers time to play (as students would) and make connections of ethnomathematics with the Emirati culture. The research team provided the teachers with several examples for ethnomathematics activities that could be used in the UAE content. During visit two, the teachers were offered the opportunity to explore the Math App, again allowing the teachers to play and interact as students would. No formal theory or framework was implemented in visits one or two, since we wanted to allow the teachers time to play with our Math App with ease. It should be noted that teachers were not included as participants of the study. During the third and final visit, the students were given access to the Math App for a total of two hours. As stated earlier, the Grade 6 classes that were asked to participate in the study were chosen exclusively by the principals of the schools. Not every section of Grade 6, from one school, was selected for participation in the research study. In other words, if a Grade 6 teacher taught five sections of Grade 6, various sections were given the opportunity to participate. The research team was not included and not aware of the selection process. After the students were provided the chance to use the Math App for two hours, they were then asked to complete a 15-min survey.

2.4. Data

The Survey. The survey consisted of nine Yes/No questions and one question about each participating student's mathematics grade. Three examples of Yes/No questions were, "Do you like math? Do you like to do math homework? Should your school allow students to learn math using a mobile device?" Since the students were Grade 6 English language learners, the research team avoided making a wordy survey that could confuse the students. The survey was adapted from Johnson and Corey (2020) to allow the research to capture the Grade 6 Emirati students' attitudes towards mathematics and learning of mathematics.

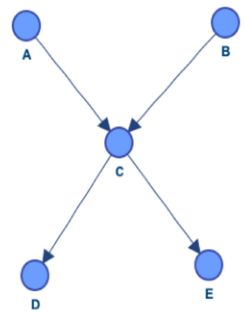
Data Collection. The lead researcher borrowed 30 mobile devices from Zayed University and loaded the Math App onto each device. He then traveled to the various schools with enough copies of the research survey on various days. While at the school, classes were suggested based on the administration guidelines (no guidelines were offered to the research team). The Grade 6 Emirati students were allowed two hours to work with the Math App. The people in the classroom were the classroom teacher, a math specialist, the lead researcher, and the students. The number of students varied from one school to another. When possible, the students were grouped in pairs based on the teacher's recommendations. This allowed students to work with a friend. Since the students in the study were identified as English language learners, we wanted the students to work in pairs while using the Math App, although each student completed the research survey independently. At the end of the students' exploration of the Math App, they were presented with a paper copy of the research survey. The lead researcher then collected the completed surveys from the students.

Data Analysis. The survey data were analyzed using the Bayesian Networks (BNs) framework. It was determined that BNs would be the best tool to analyze the data based on the descriptions and probabilities provided by BNs. Because BNs are powerful graphic models that represent the joint probability distribution (JPD) for a set of random variables, the research team sought BNs for data analysis [49–53]. Accordingly, the current research made use of the various variables and probabilities that were of importance. A BN consists of a set V of random variables connected by directed edges (without cycles), and for each random variable x of V with parents $p(x)$, a conditional probability table (CPT) is associated. To be precise, for each variable x, we attach $\Pr(x|\mathrm{p}(x))$, the probability of x conditioned by its parents $p(x)$. The set $p(x)$ consists of all variables y such that there is a direct link from y to x.

The JPD of a BN factor can be plotted according to a directed acyclic graph, namely, the JPD can be expressed as the product of the probability distribution of each variable conditioned by the set of its parents, that is, $\Pr(\mathrm{V}) = \prod_{x \in \mathrm{V}} \Pr\left(x \middle| \mathrm{p}(x)\right)$. It is essential to mention that this BN does not contain any causal assumptions. Thus, the interpretation of this network should be merely statistical. In fact, BNs allow the capturing of all possible connections, direct and indirect cause–effect, between the variables in the system. BN also allows easy visualization, not only of the joint probability distribution over all variables in the graph, but also of all possible independences and conditional independences (Figure 1).

False	True
35.000	65.000

Male	Female
60.000	40.000



A	B	False	True
False	Male	10.000	90.000
	Female	60.000	40.000
True	Male	30.000	70.000
	Female	70.000	30.000

C	Yes	No
False	20.000	80.000
True	40.000	60.000

C	Yes	No
False	38.000	62.000
True	56.000	44.000

Figure 1. An example of a BN with four variables.

The BN allows easy visualization and interpretation of the relationships among the four variables (Figure 1). Variable A has two states, True and False, with marginal probabilities (0.35, 0.65). Variable B has two possible states, Male and Female, with probability 0.60 and 0.40, respectively. Variable C has two states, True and False, while D and E each have Yes and No as possible values.

Figure 1 illustrates five basic relationships in the BN. First, A and B are independent. In fact, A and B are root nodes because they do not have any parent and, therefore, have marginal probabilities. The absence of the link between A and B means that they are marginally independent, not correlated. Second, C depends on A and B (A → C and

B $\rightarrow$ C). That is, variable C has A and B as parents, suggesting C is correlated with both A and B, and therefore, its probability table depends on both parents' values. From this convergent relationship towards C, if new information (evidence) is available for C, A and B will become conditionally dependent, as they are correlated with C. If C is known or observed, we can make inferences about A and B, but new information about A is not needed to make inferences about B and vice versa. Third, the variables C and D are directly dependent. This direct relationship (C $\rightarrow$ D) suggests that the probability of C will change if any new information for D is made available. In this case, the conditional probability of D, provided the values of its parent C, is provided as a CPT as shown in Figure 1. Fourth, B and D are independent, conditional to C. In fact, the serial connection between B and D through the path going through C (B $\rightarrow$ C $\rightarrow$ D) means that B and D are not independent, but they are conditionally independent if information for C is available. Fifth, there are two direct relationships connecting three variables, C $\rightarrow$ D and C $\rightarrow$ E (divergent connection), which causes D and E to become conditionally independent if C is known. Intuitively, this case is similar to the serial cases, and it means that D and E are not independent, but they are conditionally independent if information for C is made available. The JPD of the BN, in Figure 1, can be written as: $\Pr(A, B, C, D, E) = \Pr(A)\Pr(B)\Pr(C|A, B)\Pr(D|C)\Pr(E|C)$.

The marginal probability distributions of the three variables C, D, and E can be computed by Bayes Theorem, Pr(C) = (0.404, 0.596), Pr(D) = (0.319, 0.681), and Pr(E) = (0.487, 0.513). The possible relationships among the different variables in the BN would affect the probability of all other variables in the BN. For example, if only females were involved, assume that Pr(B = Female) = 1, and Pr(B = Male) = 0; entering this evidence on the BN will update the marginal probabilities of C and D but not A, because it is independent of B. The new probability of C with the new information: Pr (C\B = Female) = (0.665, 0.335), Pr (D\B = Female) = (0.267, 0.733), and Pr (E\B = Female) = (0.44, 0.56). In the BN (in Figure 1), the probability of C = False increased from 0.404 to 0.665, the probability of D = Yes decreased from 0.319 to 0.267, and probability of E = No increased from 0.513 to 0.56 when only Females were considered, which reflects the fact that gender (B) has a positive effect on C and E but a negative impact on D.

Based on the BN, it is possible to investigate the effect of any new evidence about one of the variables on the whole network and in each of the variables. Once the structure and the parameters—the CPTs—of the network are determined, it is possible to use the what-if sensitivity analysis for any query regarding the BN. Additionally, if new information is available, it will update the probabilities of all other variables in the BN. The marginal probability distributions, based on new evidence, can be computed by simply using Bayes Theorem.

Reliability, Consistency, and Cronbach's Alpha. BNs can be built either by using expert knowledge or by only using collected data and learning algorithms. Building a BN is therefore defining a model graph and then defining the probability tables for each variable, conditional to its parents. A learning BN consists of finding the model that best fits the available data through two main classes of algorithms: constraint-based and score-based. Thus, the search space relates to the number of variables and to the number of arcs and values. There exist a large number of algorithms for BNs; for our research study, we used Unsupervised Structural learning implemented within BayesiaLab. We did not assume any order or relationship between the variables, and we chose the model that minimized the minimum description length (MDL) score defined on BNs. The reliability and the consistency, in this case, means checking that the BN model is the best compact representation of the joint probability distribution of the data. Table 1 shows all statistics related to the estimation of the quality of the used learning method; K-fold is used for using different learning and testing sets in order to estimate the quality of the learning method and, therefore, the resulting BN.

Table 1. Evaluation of the Target Allow_Culture_Math (Yes).

Model	Result
R	0.2763
R^2	0.0764
RMSE	0.2802
NRMSE	28.0205%
Overall Precision	90.62%
Mean Precision	50.00%
Overall Reliability	82.13%

To evaluate the performance of the model, we evaluated the joint probabilities of all the observations described in the data, where the probability of each instance of the dataset is computed using the BN structure. That is, the lower the probability, the higher the cost to encore the information in the dataset (see Figure 1). Additionally, the density graph in Figure 2 summarizes the distribution of the log-loss values corresponding to the multidimensional observations described in the dataset. The global performance index of the network over the data consists of the entropy obtained with the fully connected BN. When we assume all variables are dependent, the normalized entropy obtained with the fully unconnected BN. However, when we assume all variables are independent, the contingency table represents the degree of fit between the BN joint probability distribution and the data. The deviance measures the difference between the average log-likelihood of the BN and the data.

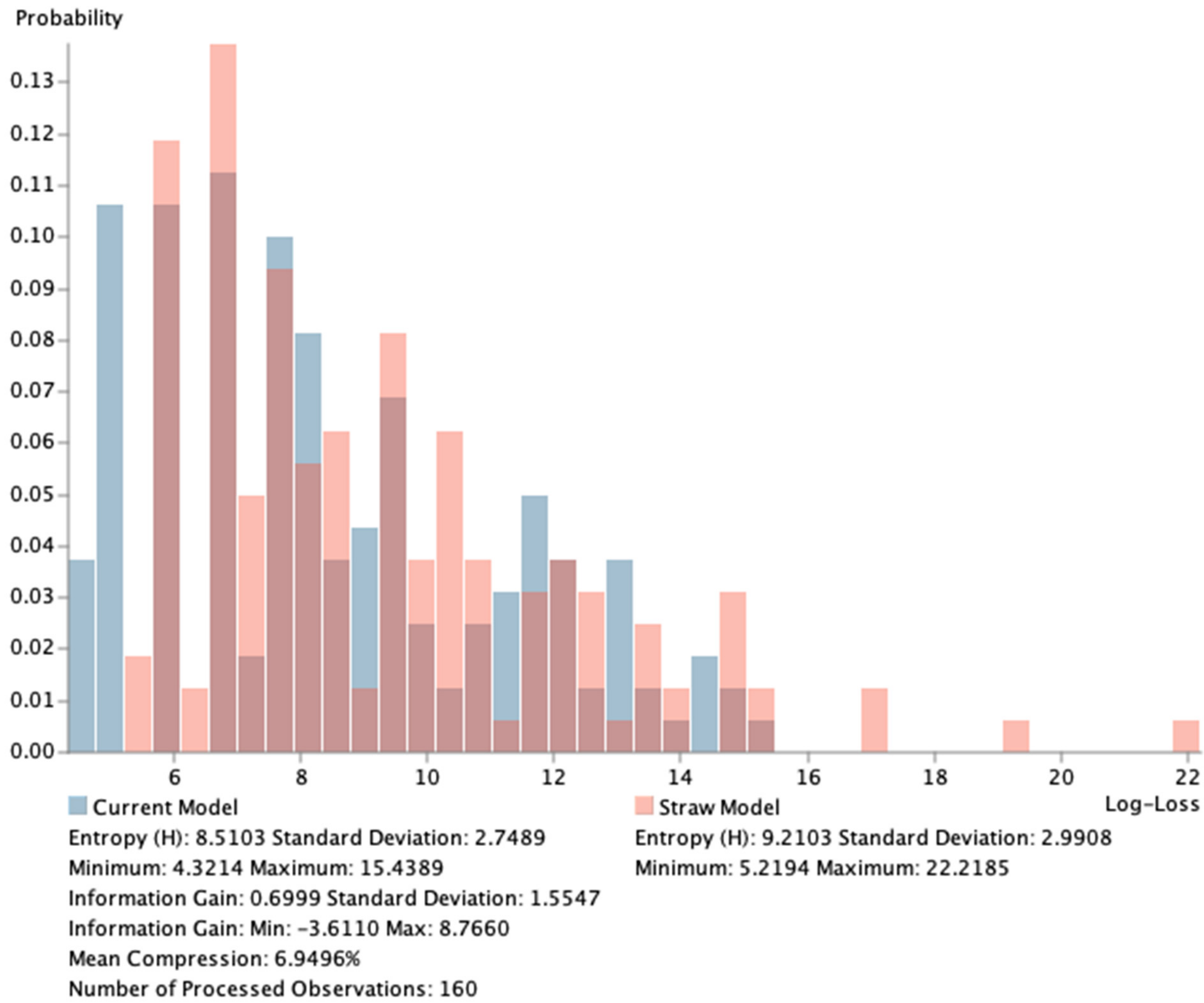


Figure 2. The BN network performance.

In practice, BNs are considerably more complex than our example, using tens, hundreds, or even thousands of variables. BNs have been widely used in decision-making domains, including but not limited to computer sciences, medical, and telecommunication applications [54–56]. They are now being used in the analysis of survey data in social and socio-economic disciplines [57,58].

3. Results and Discussion

The aim of the study was to present Grade 6 Emirati students with an opportunity to explore an ethnomathematics app that contained mathematics modules based on the Emirati culture. The research team sought educational implications discovered in the analysis of the Bayesian Networks. In the following sections, we first present a discussion of the analysis of the Bayesian Networks. Subsequently, the implications of the impact of important variables—*culture*, *mobile device*, both *culture* and *mobile device*, and *gender*—on the Bayesian Network will be explored.

3.1. The Bayesian Network

BayesiaLab Software was used to generate and analyze the Bayesian Networks. In order to generate the BNs, the survey data were arranged in 160 rows (one for each student) and 11 columns (one for each variable—each survey question including the additional question: male or female). Coding was conducted to initiate the use of the BayesiaLab Software (see Table 2).

Table 2. Bayesian Network Coding from the Survey.

Bayesian Network Software Coding	Survey Question
Gender	1 *. Male or Female.
Like_Math	2. Do you like Math?
Current_Mark	3. What is your current mark in math? A, B, C, D, or F.
Learn_Math_Today	4. Did you learn mathematics today?
Ipad_Used_Not_Today	5. Have you used an iPad to learn Mathematics (not including today)?
Allow_Culture_Math	6. Should your school allow students to learn mathematics based on the UAE culture?
Connect_To_Math	7. Were you able to connect to some of the math problems?
Confusing_To_Read	8. Were the problems confusing to read?
Allow_Mobile_Device	9. Should your school allow students to learn math using a mobile device?
Math_Culture_Before	10. Before solving these math problems, have you solved problems that connect to the UAE culture?
Like_Math_HW	11. Do you like to do math homework?

* Question was not listed as a survey question; surveys were categorized by schools (male or female).

The BN was generated purely from the survey data. BN analysis was used to obtain the most appropriate BN. Each CPT for each variable was computed from the data as well without any approximation, as there were no missing values in the data. The obtained BN is provided in Figure 3.

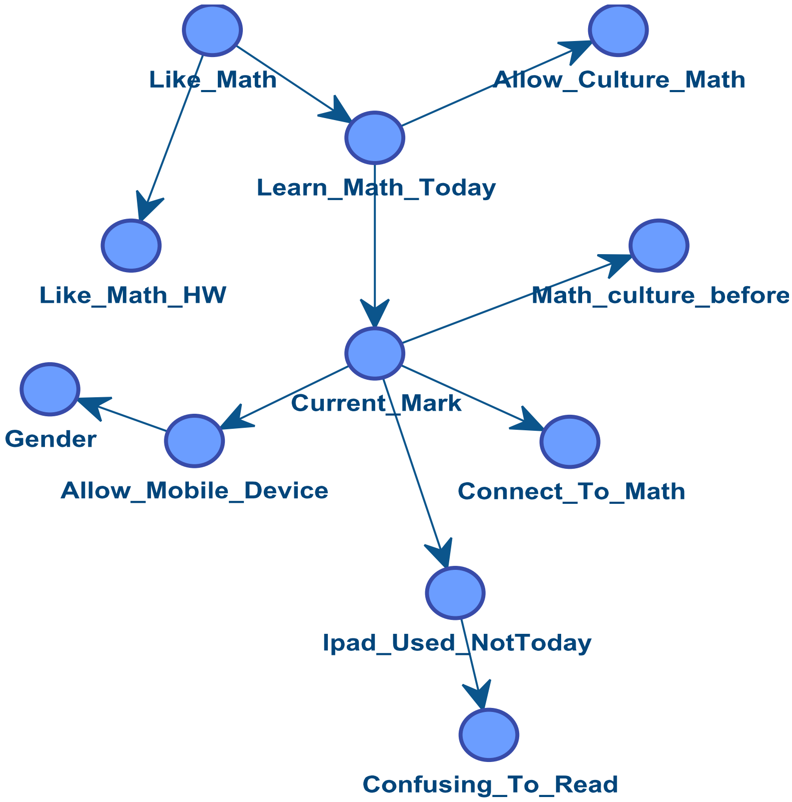


Figure 3. BN representing the data.

A list of relationships among the variables was read from the BN (Figure 3). Each link in the BN joining two variables indicated the existence of a strong correlation between the two connected variables. For instance, the BN showed that the variable Gender was only directly connected to Allow_Mobile_Device and was independent from all other variables knowing the value of its parent Allow_Mobile_Device. The BN also showed that Confusing_To_Read depends only on its parent Ipad_Used_NotToday. Moreover, Like_Math was related to Like_Math_HW and Learn_Math_Today. Like_Math and Allow_Culture_Math were independent from all other variables, conditional to its parent. Additionally, Like_Math was a parent to both Like_Math_HW and Learn_Math_Today. Like_Math and Allow_Culture_Math were independent, even knowing whether students Learn_Math_Today. However, Learn_Math_Today was independent from all the other variables, conditional to Like_Math. Finally, Like_Math_HW was strongly correlated to Like_Math.

In addition to the dependency between Like_Math_HW and Like_Math from one side, and from the other side Like_Math_Today and Learn_Math, there was an indirect dependency between Learn_Math_Today and Like_Math (this was true for the paths Like_Math_HW ← and Like_Math → Learn_Math_Today). Moreover, there was an indirect dependency between Allow_Culture_Math and Like_Math. This suggests that, without any knowledge about students who Learn_Math_Today, permitting the use of Allow_Culture_Math increased the students who Like_Math (this was true for the paths Like_Math → Learn_Math_Today → Allow_Culture_Math). Furthermore, the dependency between Like_Math_HW and Like_Math from one side, and from the other side Like_Math_Today and Learn_Math, was an indirect dependency between Learn_Math_Today and Like_Math_HW (this was true through the diverging path Like_Math_HW ← Like_Math → Learn_Math_Today). This result suggests that Learn_Math_Today and Like_Math_HW were independent, conditional to whether or not students Like_Math. However, there was an indirect dependency between Allow_Culture_Math and Like_Math, suggesting that, without any knowledge about whether students Learn_Math_Today, permitting Allow_Culture_Math increased students who Like_Math (this was true through the serial path Like_Math → Learn_Math_Today → Allow_Culture_Math). Moreover, there was an indirect dependency between Allow_Mobile_Device and Connect_To_Math. In fact, not knowing anything about students' grades in mathematics, allowing them to use a mobile device increased the students' connection to Math (this is true through the diverging path Allow_Mobile_Device → Current_Mark → Connect_To_Math) (Figure 4).

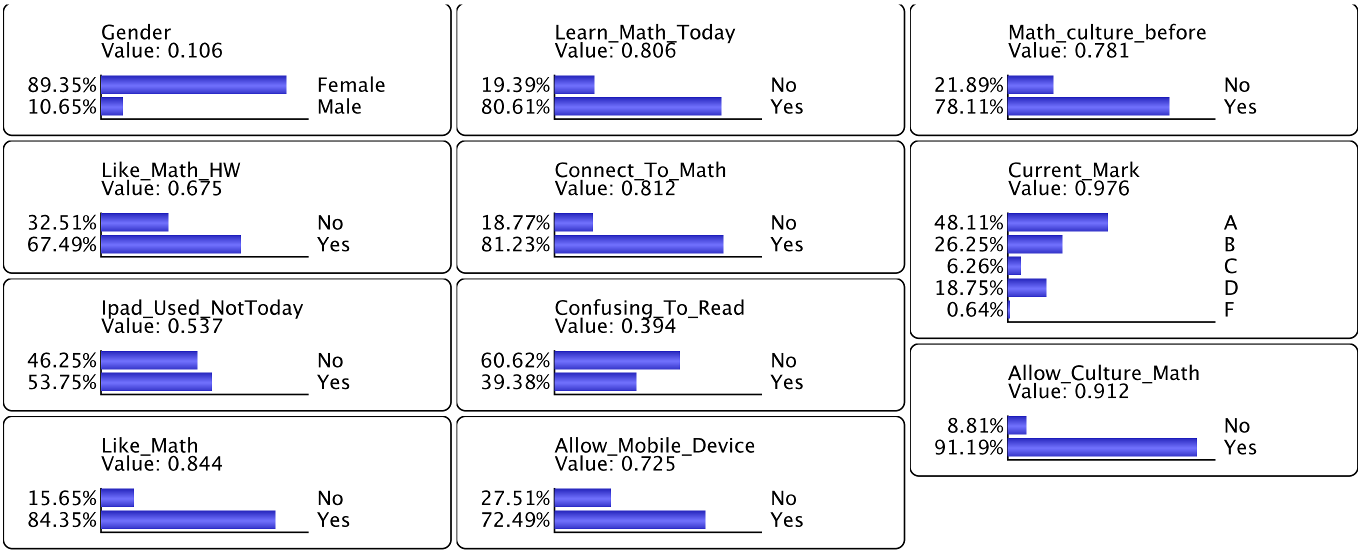


Figure 4. Marginal probability associated with each of the BN variables.

The next step after generating the BN structure was to compute the parameters of the BN. The marginal probability of all BN variables is provided in Figure 4. We decided to show only the marginal probabilities and not all CPTs, as they were numerous and large.

Last, a what-if analysis was run using the two important variables: Allow_Culture_Math and Allow_Mobile_Device. These variables were deemed important since the research centered on the notion of culture and a mobile device. Nevertheless, gender was later investigated due to our attempt to observe the influence of gender on the BN. The what-if analysis was used to determine the impact of these variables on all other variables.

3.2. First Important Variable: Allow_Culture_Math

If the variable Allow_Culture_Math was set to 100%, the percent of Learn_Math_Today increased from 80.61% to 84.23, Like_Math_HW from 67.49% to 68.02%, and Like_Math from 84.35% to 85.39% (Figure 4). Conversely, if the variable Allow_Culture_Math was set to no, Learn_Math_Today decreased from 67.49% to 61.95% and Like_Math from 84.35% to 73.61%. There was also a drop in Learn_Math_Today probability from 80.61% to 43.07%. Based on this BN, allowing Emirati students opportunities to explore mathematics based on the Emirati culture showed a clear impact on Like_Math, Like_Math_Homework, and Learn_Math_Today.

It was important to note that Allow_Culture_Math increased slightly high grades, such as grades A and C. However, no Allow_Culture_Math doubled the percent of lowest grade F and decreased the percentages of the highest grade A. This suggests that if Emirati students were allowed to explore mathematics based on the Emirati culture, students with grades A and C would show slightly higher grades. However, if Emirati students were not allowed to explore mathematics based on the Emirati culture, more students would have a grade of F, while some A students would have a lower grade.

3.3. Second Important Variable: Allow_Mobile_Device

If Allow_Mobile_Device was set to yes, the percent of males increased from 10.65% to 13.81%, while the percent of females was reduced by 3.17% (Figures 5 and 6). This suggests that a strong indication of male students would be more likely to ask that a mobile device be allowed in their school. Additionally, Allow_Mobile_Device increased the probability of the following variables: Like_Math, Learn_Math_Today, Connect_To_Math, and Allow_Math_Culture. However, Confusing_To_Read decreased from 39.38% to 38.75%.

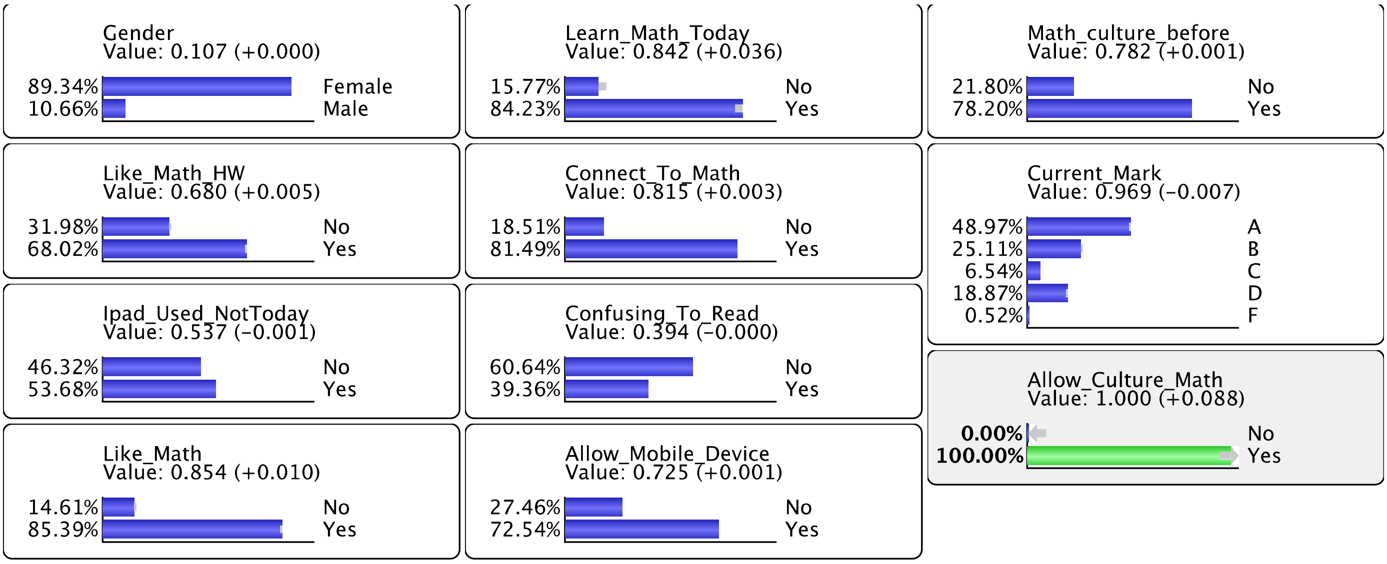


Figure 5. Marginal probability associated with each of the BN variables provided the information that Pr (Allow_Culture_Math = Yes) = 100%.

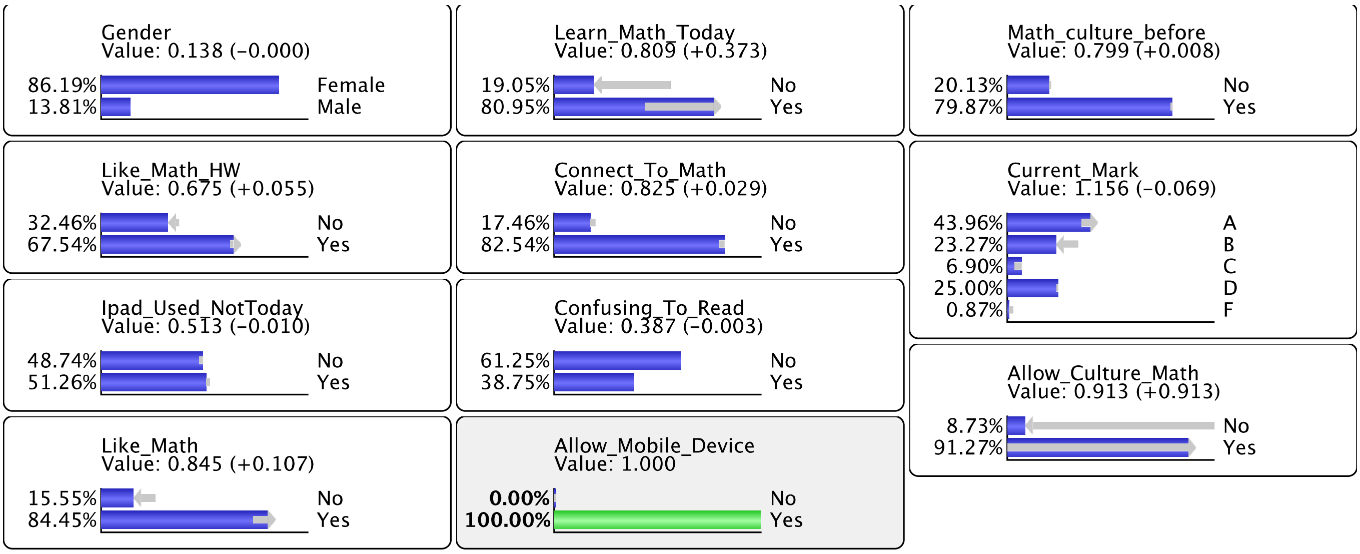


Figure 6. Marginal probability associated with each of the BN variables provided the information that Pr (Allow_Mobile_Device = yes) = 100%.

3.4. Both Important Variables: Allow_Mobile_Device and Allow_Culture_Math

The team examined the impact of allowing both Allow_Mobile_Device and Allow_Culture_Math on the BN (Figure 7). It was determined that the combined influence slightly increased Confusing_To_Read and somewhat increased the likelihood of Like_Math, Like_Math_HW, and Connect_To_Math. However, Learn_Math_Today significantly increased from 80.61% to 84.52%. Additionally, Like_Math increased from 84.35% to 85.47% when Allow_Culture_Math and Allow_Mobile_Device were both observed.

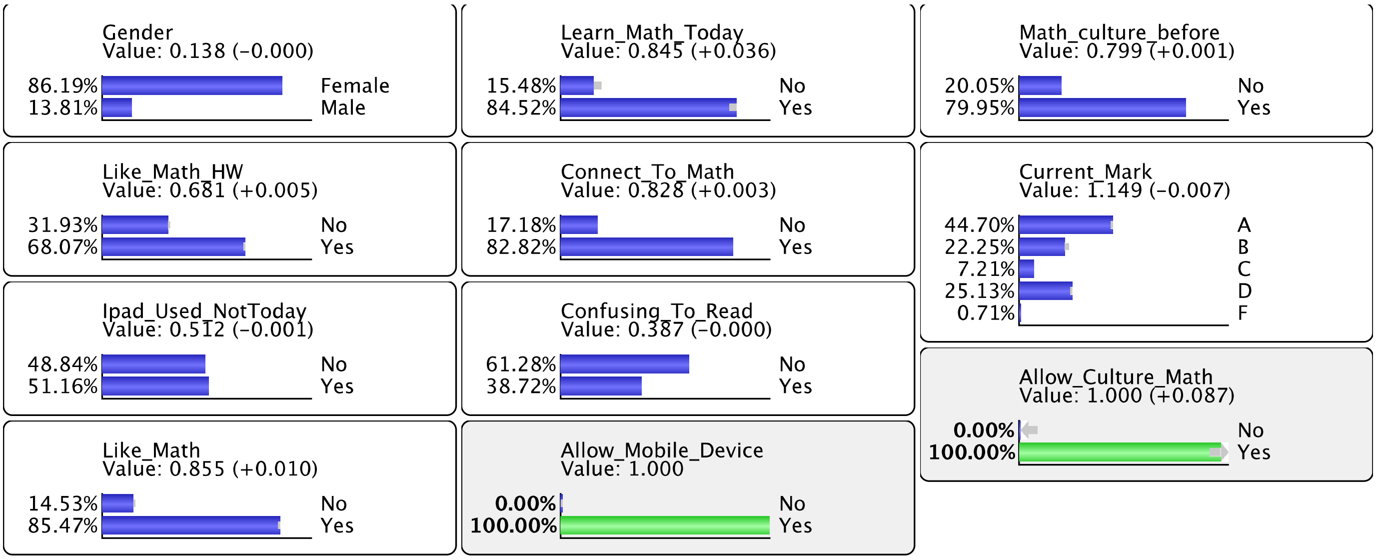


Figure 7. Marginal probability associated with each of the BN variables provided the information that Pr (Allow_Mobile_Device = Yes) = Pr (Allow_Culture_Math = Yes) = 100%.

Conversely, the combined impact of Allow_Culture_Math and not Allow_Mobile_Device was similar, but with different probabilities as not Allow_Culture_Math and Allow_Mobile_Device (Figure 8). When Allow_Culture_Math and not Allow_Mobile_Device were observed, the result increased Learn_Math_Today from 80.61% to 83.46% and Like_Math from 84.35% to 85.17% (Figure 8). However, when not Allow_Culture_Math and Allow_Mobile_Device were observed, the outcome dramatically decreased Learn_Math_Today from 80.61% to 43.62% and Like_Math from 84.35% to 73.76% (Figure 9). Based on these results, Allow_Culture_Math had a positive change in liking and learning mathematics, even without a mobile device. However, not Allow_Mobile_Device and not Allow_Culture_Math had an increased negative impact on Like_Math and Learn_Math_Today.

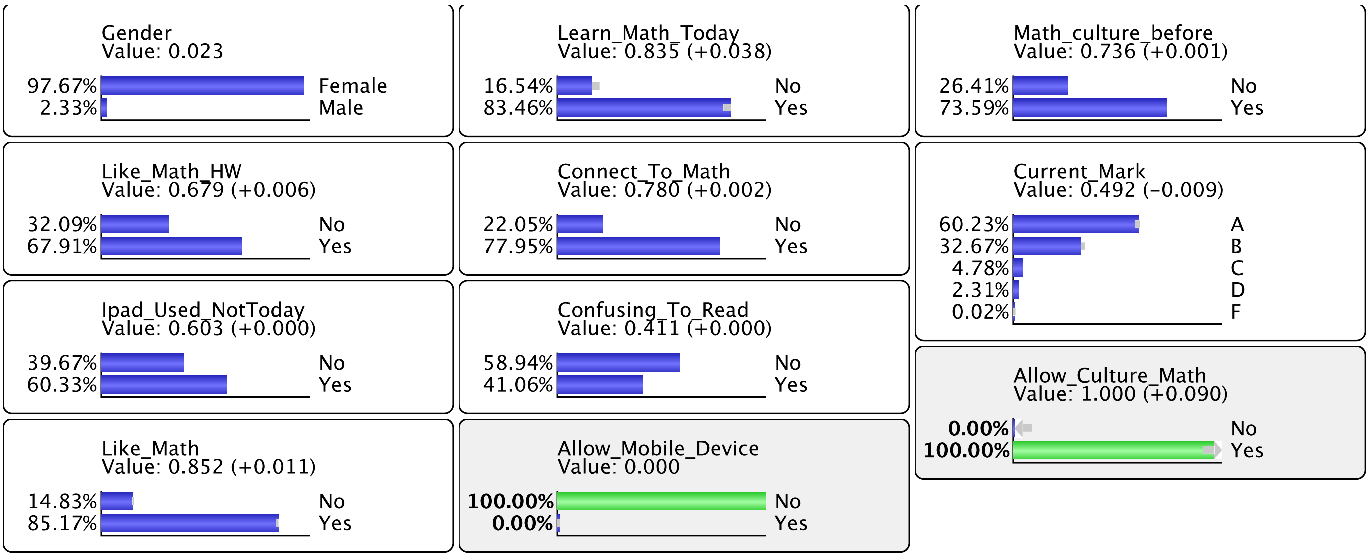


Figure 8. Marginal probability associated with each of the BN variables provided the information that Pr (Allow_Mobile_Device = No) = 0 and Pr (Allow_Culture_Math = Yes) = 100%.

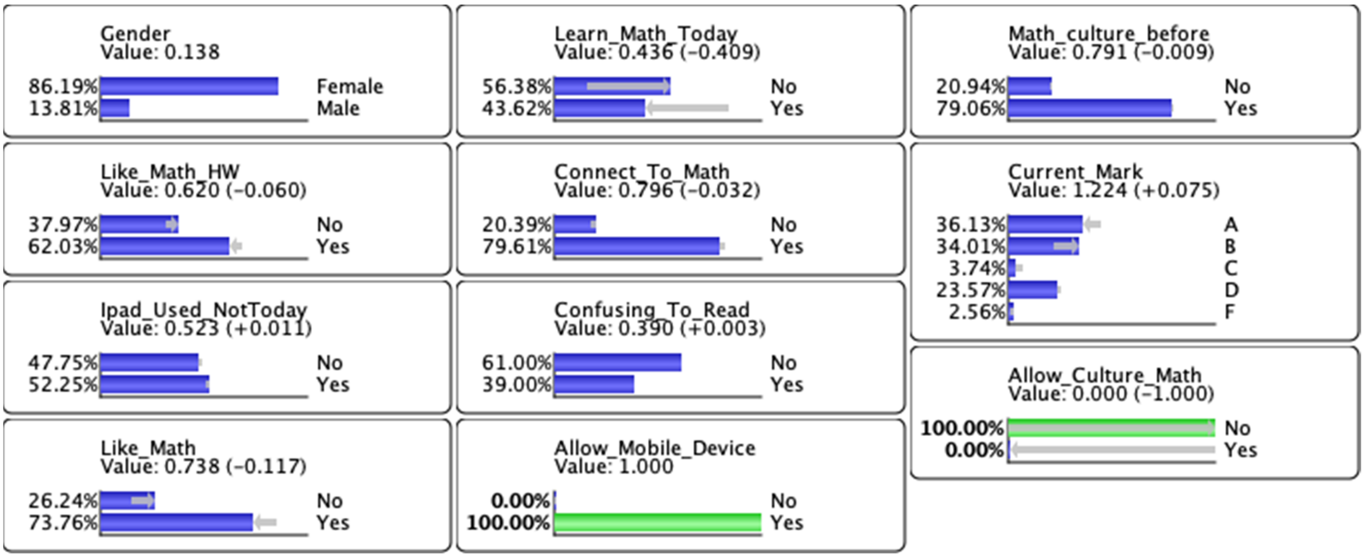


Figure 9. Marginal probability associated with each of the BN variables provided the information that Pr (Allow_Mobile_Device = Yes) = 100% and Pr (Allow_Culture_Math = No) = 0.

3.5. Gender Variables: Male or Female

An additional analysis was sought to examine the influence of gender on the variables of the BN, even though gender was not part of the initial research question. By fixing gender to only females (Figure 10), then to only males (Figure 11), both influenced the gender preference for Allow_Mobile_Device. By fixing gender to female, the likelihood of not Allow_Mobile_Device increased from 27.51% to 30.08%, while fixing gender to male, the likelihood of Allow_Mobile_Device increased from 72.49% to almost 94%. It appeared that male students were more likely than female students to ask for Allow_Mobile_Device in their schools even though the number of males in the chosen sample was only 13.81% as shown in Figure 9.

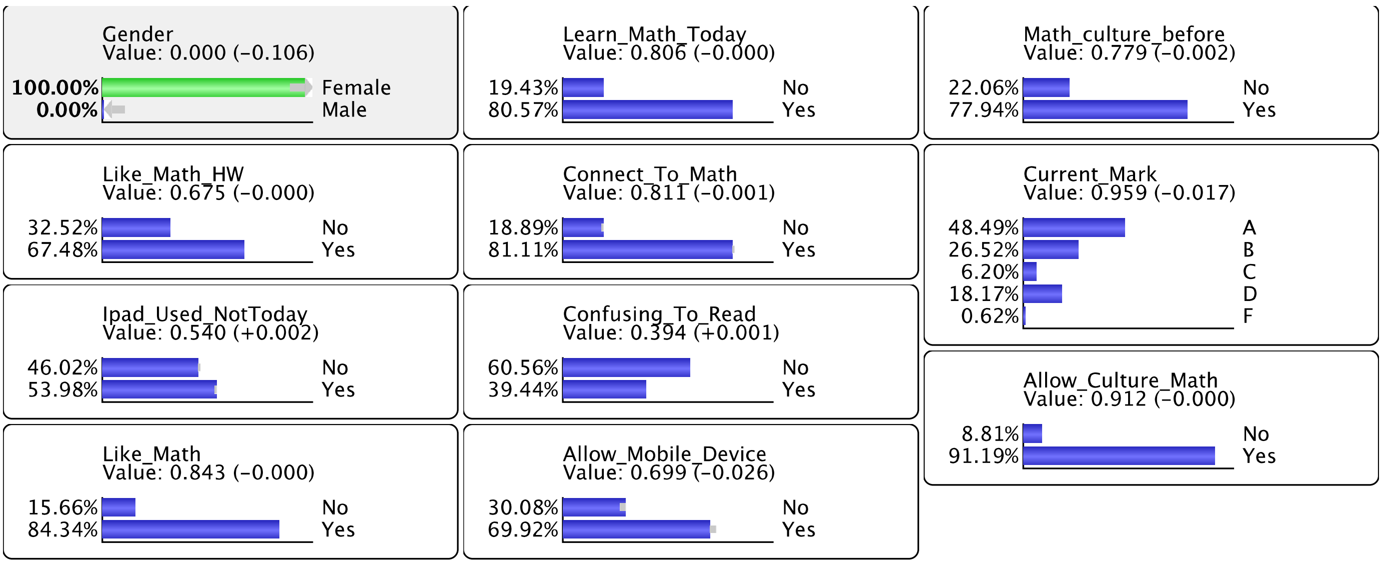


Figure 10. CPT associated with each of the BN variables provided the information that Gender = Female.

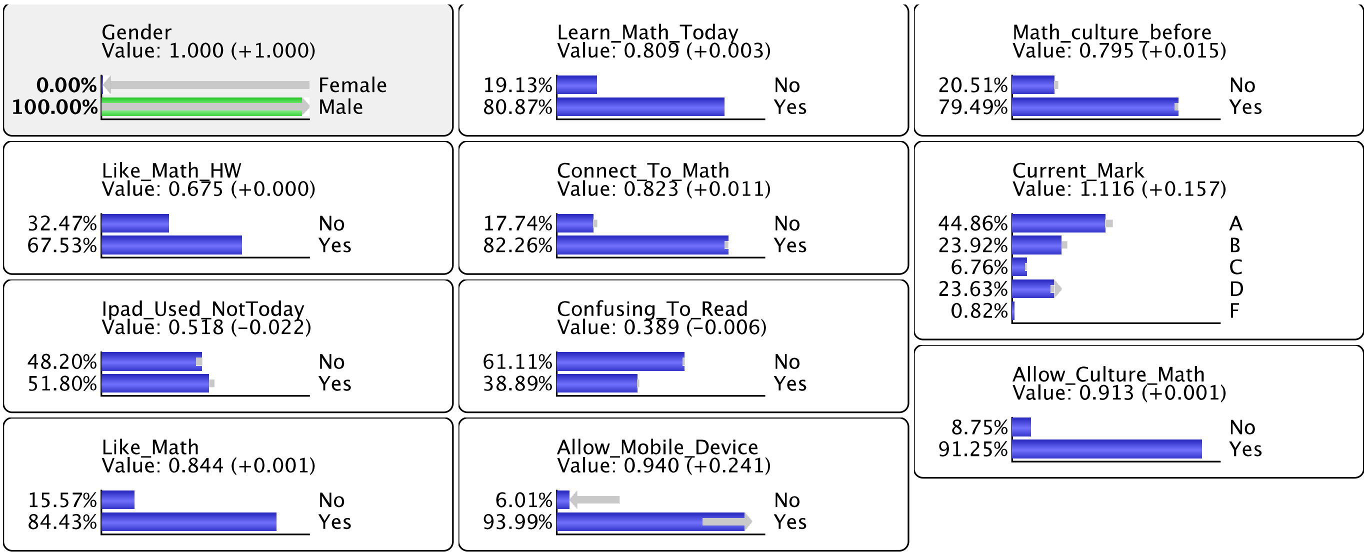


Figure 11. Marginal probability associated with each of the BN variables provided the information that Gender = Male.

4. Implications

The purpose of the study was to provide Grade 6 Emirati students with the opportunity to use an IOS mathematics app that contained mathematics modules based on the Emirati culture. Through the use of BNs as a framework, it was revealed that the Grade 6 Emirati students desired mathematics problems based on the Emirati culture. This was true for boys and girls. The Middle East and Islamic Culture have proven beneficial to Western mathematics. Similarly, Berggren [59] reported on the significant advances of arithmetic, algebra, spherical trigonometry, mechanics, optics, and cartography by Islamic mathematicians. The teaching of ethnomathematics in the Middle East and its history could encourage student mathematical achievement. Instead of learning mathematics using Western examples, students should learn mathematics using their native culture [60]. One intent of the current research study was to allow students to make a connection to mathematics via ethnomathematics or ethnomathematics via mathematics. Amit and Qoudar [16] stated that "Integrating cultural elements into the mathematics curriculum encouraged the students' family members to become actively involved in their schoolwork" (p. 28). Moreover, Karssenberg [31] reported that Muslim students and their parents in Dutch schools appeared more interested in supporting learning when the curriculum incorporated a cultural perspective. The current study did not explore the notion of students' parent involvement; however, this idea could be explored further in future projects.

Finally, for those who do have the opportunity to use ethnomathematics in school mathematics, its application can make mathematics more relevant and applicable for *all* students [60]. Utilizing ethnomathematics creates an environment for students to understand their cultural and historical background [31]. In the IOS Math App, Emirati students explored: henna, prayer beads, and bamboo baskets. These are all extremely recognizable in the Emirati culture and are vastly used by Emiratis. Henna drawings are popular during weddings, birthdays, and special events. Prayer beads are widely recognizable by Emirati individuals. Bamboo baskets are found everywhere in the UAE, and the older generation still creates such baskets by hand. We believe the above results and analysis provide evidence for using mathematics modules based on the Emirati culture with Emirati students, and as such, this pedagogical approach can be a unique opportunity to make connections and afford agency. It is worth mentioning that although the word "culture" may not resonate with the same set of traditions and customs common to all sixth graders involved in our study, we limit its use to the shared conventional meaning of the term. Culture is generally considered to be the set of beliefs, knowledge, customs, arts, regulations, and skills of individuals in societies.

The present study can have a pedagogical implication for the use of technology to facilitate learning. It was noted that the Grade 6 Emirati boys were very keen to use a mobile device to explore the mathematics modules based on the Emirati culture. A considerable amount of research on the use of technology to assist with learning has been conducted in the Middle East. For instance, students in Kuwait revealed their satisfaction with using a mobile device in their learning and believed that the device improved their knowledge of the English language [61]. Additionally, Nassuora [62] findings demonstrated that mobile learning had a high level of acceptance among Saudi Arabia students [62]. The current study did not explore the notion of Emirati students' ability to communicate with mobile learning, while students in Saudi Arabia reported positive attitudes towards mobile learning and improved communications [63]. Moreover, Tuparov et al. [64] determined that, while students had positive attitudes towards the use of mobile learning in their education, the universities in Yemen did not offer sufficient mobile learning resources. We did not explore the notion of what schools or universities offered with respect to mobile learning policies and/or resources for students.

Conversely, the girls in our study did not like learning mathematics using a mobile device. This finding was not consistent with research in the Middle East. Alfarani [65] found that female Saudi Arabia teachers expressed positive potential for the use of mobile learning to enhance collaboration among students. Furthermore, Al-Fahad [66] determined that mobile learning improved female students' knowledge retention and enhanced students' learning process. Both suggested that females in the Middle East do, in fact, have positive dispositions for the use of mobile learning.

The last implication concerns the concept of using cultural examples in conjunction with mobile learning. We were hopeful that the combined effect of Allow_Culture_Math and Allow_Mobile_Device would be more impactful than just Allow_Math_Culture. On the contrary, the Grade 6 Emirati students reported that Allow_Culture_Math is more important than Allow_Mobile_Device in learning. The reason could be that 72.4% of all surveyed students stated "yes" to Allow_Mobile_Device, while 90.4% indicated "yes" to Allow_Culture_Math. Since this concept for using ethnomathematics and mobile learning in the Middle East was fairly new, no other research studies could be examined or analyzed. Again, the students in the study valued using ethnomathematics examples over mobile learning.

In the end, how do the research findings and implications contribute to the scientific community? As for the ethnomathematics research community, our research findings are consistent, that students prefer to learn mathematics using a cultural lens that represents the students. As for the mobile learning community, our results are not consistent with the literature. The girls in our study preferred not to use mobile learning to learn mathematics. It was also noted that both girls and boys reported that mobile learning was not significant to learn mathematics. Additionally, the girls and boys in our study described the use of ethnomathematics as more beneficial for learning than a mobile device.

5. Limitations and Future Research Extensions

There were some limitations to the current study. The first limitation was the age of the Grade 6 Emirati students to fully engage with the ethnomathematics modules and survey. The lead researcher made every attempt to discuss all students' questions in Arabic and/or English. Another limitation was the student bias while working in pairs to complete the ethnomathematics modules. Abulhassan and Hamid [67] reported that Arabic children who were paired with other Arabic children work best in pairs. Pairs of English language learners are typically able to complete a task with ease [68–70]. Since our research study population was comprised of English language learners, some students could have been confused with the survey questions, although we conducted a pilot study to explore the language of our survey and made improvements based on the pilot study results. It should be noted that the lead researcher was particularly cognizant of this limitation. He communicated with the classroom teacher to identify any student who needed the survey in Arabic and/or English. Another possible threat to the research study was the time students were allowed to explore the ethnomathematics modules. Students were only allowed 2 h to explore two or three modules. The principals for all the schools that participated in the research study were extremely willing to allow the team into the school; however, time constraints were a major impeding factor. The last limitation was the small sample size. It was exceedingly difficult to find schools that would allow the research team into their school and take three days out of their teaching calendar. Nevertheless, the schools that did allow the research team onto their campuses were willing to accommodate the team with the required three days.

In light of the above, we believe future research studies must be completed to continue the research in this area to improve the learning and teaching of mathematics for Emirati Grade 6 students. One study could examine a longitudinal investigation on the impact of students using ethnomathematics modules. Do these experiences encourage students to consider additional STEM courses? Additionally, studies could explore the impact of such experiences on a student's future career goals and willingness to register for higher level mathematics. Another study could explore the concept of students' parental involvement. That is to say, when students complete ethnomathematics modules, do parents take an active role in their students' education? Another study could explore the notion of using ethnomathematics as a means to confront classroom management. What are the implications for teachers who use ethnomathematics in their classroom, as it pertains to classroom management? Finally, a study could examine school or university policies geared toward student mobile use. Do such policies encourage students to use mobile learning instead of laptops and/or desktops?

6. Conclusions

The goal of the study was to provide Grade 6 Emirati students with an opportunity to use a newly developed IOS Math App, which contained mathematics modules based on the Emirati culture. By doing so, implications for learning were sought. To discover these implications, survey data were analyzed using Bayesian Networks. The findings suggested that if Emirati students were allowed to explore mathematics based on the Emirati culture, students with grades A and C would show slightly higher grades. However, if Emirati students were not allowed to explore mathematics based on the Emirati culture, more students would have a grade of F, while some students with grade A would be lowered. Additionally, the findings showed that incorporating cultural phenomena, perceptions, and preferences had a positive influence of students' liking and learning mathematics, even when a mobile device is not used in the process of teaching and learning. However, failure to include a mobile device and cultural elements had an increased negative impact on liking and learning mathematics. Finally, the findings suggested that students valued using ethnomathematics examples over mobile learning. The findings presented in this research study may help to improve sustainability in mathematics education by promoting ethnomathematics and mobile learning. In subsequent research, a larger sample could be used to explore the possible implications based on the BN. Additionally, future IOS apps could include STEM modules along with the design thinking process.

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