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Principal components of students' difficulties in mathematics in the purview of flexible learning

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Abstract

The abrupt migration of educational institutions into a more flexible mode of learning due to the COVID-19 pandemic has undoubtedly resulted in students' difficulties. Such difficulties specific to mathematics flexible learning are generalized in this quantitative study. Using Principal Component Analysis, seven (7) factors were identified as the emerging students' difficulties. Further analyses reveal a moderate degree of seriousness for most of the components. However, the standard deviation suggests that the students' responses are spread across the measuring scale, indicating that the severity of difficulties experienced by other students is higher than moderate. Further comparison of such ratings shows that for students enrolled in advanced and major mathematics courses, difficulties emanating from inadequate learning materials and support, and difficulty in submitting requirements on time are more pronounced. These intertwined difficulties generally stem from the lack of planning and preparation, at the same time from the nature of mathematics as being complex, abstract, and notational. By considering these difficulties, adjustments may be prioritized by students and teachers in the hope of improving the current state of mathematics flexible learning. These improvements will eventually lead to sustainable and fully stable online academic programs that may be offered even after the pandemic.

Keywords: Flexible Learning, Mathematics, Principal Component Analysis, Students' Difficulties

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The outbreak of the novel coronavirus (COVID-19) which evolved into a full-blown global pandemic during the earlier months of 2020 (Cucinotta & Vanelli, 2020), has disrupted almost all aspects of life especially around education. Particularly, the pandemic made it impossible for students to continue their education in the physical classrooms. This is to avoid or limit the risk of infection among students, teachers, and other academic personnel. In lieu of the traditional face-to-face classes, the Commission on Higher Education (CHED) has instructed higher education institutions to deploy available modes of instructions such as distance learning and e-learning (CHED, 2020a). An approach called Flexible Learning was later suggested by the same commission. Briefly, this approach allows the flexibility of time, place and audience when delivering instruction among students (CHED, 2020b). This is the approach adopted by the university where this study is conducted.

This flexible learning approach ensured the continuity of education without actually coming to the university. Consequently, the delivery of learning materials has been greatly facilitated by technology and the internet. Most students are instructed to access learning materials through platforms such as the

Google Classroom, Facebook, YouTube etc. Assessment and submission of output are also undertaken using these platforms. Also, students attend virtual classes through video conferencing services such as Google Meet and Zoom.

The role of technology has become critically significant for the successful implementation of the flexible learning approach. This created the demand for students to have access to the internet, own gadgets, and acquire some level of digital literacy. In a recently concluded study, it was shown that the ability to use information technology (IT) does not only affect the learning process but also the learning of the course content (Ramadhani et al., 2021). Moreover, the quality of distance and online learning may vary depending on the level of use and the way technology is used (Duraku & Hoxha, 2021).

Unfortunately, the flexible learning approach becomes disadvantageous for students who belong at the bottom of the digital divide. Digital divide refers to the "gap between individuals, households, businesses and geographic areas at different socio-economic levels with regard both to their opportunities to access information and communication technologies (ICTs) and to their use of the Internet for a wide variety of activities" (Organization for Economic Cooperation and Development, 2001 p. 5). The digital divide in the Philippines has been serious with nearly 60% of its households not having internet connectivity and with low high-speed broadband penetration (World Bank, 2020). This divide is also reflected in a latest national survey, showing that only 24% of the 42 816 households surveyed own a computer (Department of Information and Communications Technology, 2019). Specifically, in the Cordillera Administrative Region (CAR), 70% are non-owners of a computer. Moreover, 84.30% and 76.4% of the households do not have access to the internet in the national level and in CAR respectively. This survey also showed that the main reasons for internet inaccessibility are the high cost of the internet and the equipment needed, unavailability of internet services, inability to use the internet, and poor quality and speed. Moreover, the proportion of individuals that carried out computer-related activities in online or distance learning is only 22.1% and an even lower proportion of 8.7% in CAR. Deeper observation of the data shows that there is a disproportion in ICT access in terms of geographical locations. Households in rural or non-metropolitan areas have lower device ownership and internet access.

While students' difficulties in online learning were investigated before the pandemic, difficulties during the pandemic are expected to be different because the shift from traditional classroom lectures to online learning was unplanned. Especially since the university does not have an existing online academic system, students and teachers were left unprepared. The inexperience of instructors in using online applications has led to student difficulties (Zahara et al., 2020). In a much earlier study, it was found that success in online learning is affected primarily by the instructor's pedagogical and technical competencies (Kim & Bonk, 2006).

From the perspective of students, disruptions may also arise because the teaching-learning process happened mostly in their homes. In a qualitative study that investigated the impact of the COVID-19 pandemic to tertiary education students, it was revealed that students were unmotivated studying at home and spent more time doing other works like farming and handicrafts (Dutta & Smita, 2020). The same respondents reported that they missed social interactions such as studying with peers. Physical and mental health problems were also identified. For example, college students are affected by the pandemic on different levels such as loneliness, compromised motivation, sleep disturbances, and anxiety and depression (Tasso et al., 2021).

The learning difficulties of students may also stem from the nature of Mathematics as a discipline. For example, because mathematics involves abstract and complex ideas that are expressed in symbols and notations, communicating them online makes it more difficult for both teachers and students, especially without the appropriate equipment and technology. Teachers may also find it more challenging to recreate text or print materials for mathematics courses that are sufficient for students and require minimal support especially during asynchronous teaching. These problems were apparent in the report of (Hodds, 2020) on the changes in mathematics and statistics support practices of teachers during the pandemic and in the study of Johns and Mills (2021) describing the experiences of mathematics online tutors.

The flexible learning approach undoubtedly has limitations based on the initial responses of students since its implementation. According to the World Bank (2021), distance learning in the Philippines was not effective because students lack or have limited access to learning gadgets. The same organization asked people on the effectiveness of distance learning over face-to-face schooling. Majority (59%) said that distance learning is less than 50 percent effective, twenty-eight percent agreed it is 50-80% effective, while only fourteen percent said it is 80-100% effective. Similarly, Cho et al. (2021) have identified that students' most common concerns include the lack of access to gadgets, inability to focus on remote learning, and stress due to the pandemic.

Anchored with the above context and research gaps, this study aimed at achieving three objectives. First, it identifies students' difficulties that are specific to flexible mathematics instruction. To get the most information and visualization of these difficulties, a data reduction or compression technique called principal component analysis is utilized (Jolliffe, 2002; Li et al., 2016). Second, it reveals the degree of seriousness of the difficulties identified and reduced. With these difficulties identified, educators are given empirical evidence that may serve as basis for curricular revisions, creation of new policies, and identification of effective teaching strategies. Finally, the degree of seriousness of these difficulties are compared according to whether a student is taking a basic, advanced, or a more abstract major mathematics course. Results from these comparisons may serve as criteria for possible adjustment when conducting flexible learning in mathematics. Also, while the pandemic forced teachers and students to migrate to this approach, experiences from it may offer positive and useful methods for assisting online mathematics learning long after the pandemic is over. By identifying the emerging factors related to the quality of learning, the present state of mathematics education is improved. More importantly, it opens the door to offering stable online academic programs in the future.

Flexible Learning and Mathematics

Flexible Learning emphasizes on giving options and customization of courses to meet students' varying needs (Huang et al., 2020). Students are given choices as to the time of the class, course content, instructional approaches, learning resources and location, technology used, the requirements for entry or completion dates, and communication medium (Collis et al., 1997; Goode et al., 2007). Similarly, Lee and McLoughlin (2010) defined flexible learning as an approach that offers students the choice, convenience, and personalization to match their learning needs by using a wide range of technology.

Based on these definitions, flexible learning in this study could be purely modular (modules provided in physical form) for those students who do not have internet connection. It is also online which can be either synchronous or asynchronous, or a combination of the two for students with access to the internet. Synchronous online learning is conducted live and real-time where students and teachers can interact while asynchronous online learning uses online learning materials (e.g., prerecorded video lectures) to facilitate learning without the constraints of time (Shahabadi & Uplane, 2015). In the case of the students involved in this study, the majority of students attended online classes and only a fraction opted for purely modular learning.

For online learning to be effective, the literature suggests important recommendations. Giatman et al. (2020) mentioned that online learning must consider several aspects such as capabilities, constraints, and economic conditions of students. Moreover, the requirements and considerations for an online course may vary depending on the nature of the course being taught. For example, in a study involving computing students, it is perceived that their academic performance in online learning is influenced by the number of devices they owned (Bringula et al., 2021).

Particularly in a mathematics online class, the following must be considered: (1) provision of technology used in the course, (2) availability of consultations, (3) creativity interacting with students, (4) provision of performance feedback, (5) encouragement of class participation and collaboration, and (6) use of varied teaching styles (Berge et al., 2000). Herrington et al. (2004) added that online activities should be relevant and varied. Previous research has also investigated the factors related to the achievement of students in online mathematics learning. For example, Wadsworth et al. (2007) claimed that strategies on motivation, concentration, information processing, and self-testing significantly predicted students' online achievement. Moreover, Glass and Sue (2008) pointed out that online mathematics classes are strongly encouraged to utilize many practice problems with fast feedback. They also suggested the integration of tools like media-enhanced lectures in the delivery of lessons. Cho and Heron (2015) finally recommended that online mathematics teachers should enhance students' self-efficacy, design supporting tools in online courseware, provide course orientation, provide support through social media, and restructure the format of the course.

To synthesize, the flexibility of learning allowed for students during the pandemic is most appropriate given the varying capacity and constraints experienced by students. However, this also makes the delivery of flexible learning challenging especially for mathematics courses because it requires much from both teachers and students.

Difficulties of Students in Flexible Learning During an Educational Disruption

When the World Health Organization declared the outbreak of the COVID-19 virus as a global pandemic, most educational institutions closed their physical learning environments and were forced to migrate from their face-to-face classes to flexible learning. Because many students and teachers were caught unprepared (Aguilera-Hermida, 2020), several requirements for online learning are barely met. For example, lack of devices, issues with the online platform and internet connectivity, financial distress, self-learning using the given materials, and difficulty studying at home due to environmental noise and distractions are the major challenges for Filipino medical students in their online classes (Baticulon et al., 2021). Fabito et al. (2021) added that computer science and information technology students had trouble in clarifying topics with their teachers. In a qualitative study conducted by Rotas and Cahapay (2020), the difficulties experienced by Filipino students were caused by unstable internet, inadequate learning materials, power interruptions, vague learning contents, overloaded activities, limited teacher scaffolds, poor peer communication, conflict with home responsibilities, poor learning environment, financial problems, and struggles in physical and mental health.

Majority of these studies emphasizes that students' difficulties stem from inadequate facilities such as gadgets and internet connectivity. Also, some of these difficulties point to the teachers' inability to provided sufficient materials and support appropriate for online learning. Students' emotional and mental state while balancing their classes and responsibilities at home appear to be a common struggle. All these difficulties appear to be a direct or indirect effect of the pandemic.

Students' Difficulties in Flexible Learning and Level of Mathematics Course

One challenge for both teachers and students in an online class is communicating mathematical contents. Consequently, there arises a need to recognize important educational and technological tools that may be used to communicate mathematics effectively (Najdi, 2020). Hodges and Hunger (2011) emphasized that mathematical conversations require the aid of appropriate communication tools. Representing ideas, principles and problems using images (visualization) has played significant roles in both teaching and learning of mathematics (Apostol, 2000). Visualization and exploration of mathematical objects and concepts done in multimedia environments can foster understanding in new ways (Hohenwarter et al., 2009; Voorst, 1999).

Because teachers are not necessarily prepared to teach online, communicating mathematical contents is hampered. For example, the creation of mathematics learning modules requires some digital skills especially when symbols and notations are to be digitized. The digitization process may require computer applications that need to be installed or need to be attached as an "add-on" to existing computer programs. The use of more powerful mathematical applications such as GeoGebra as alternative to traditional teaching techniques requires more serious digital skills. Preparing pre-recorded lectures, applets, and other support materials for asynchronous classes not only requires the use of math applications but also the technology to record, store, and upload. These were apparent in the study of Zahara et al. (2020) where teachers experienced difficulties in preparing e-learning materials because they do not necessarily know how to use online applications. Also, in the investigation of Naveed et al. (2017) on the barriers affecting the implementation of e-learning revealed that instructor-related barriers include lack of ICT skills, lack of e-learning training, and lack of time to prepare e-courses. Consistently, mathematics teachers' top barrier in implementing e-learning is lack of knowledge, skills, and experience to do so, (Mailizar et al., 2020). The same set of authors also identified that lack of ICT skills and lack of e-leaning knowledge and skills are most significant student-related barriers. This is expected since students should also know the applications or technology that their teacher uses to ensure that effective communication happens.

Depending on the nature of a mathematics course, the number of technological skills needed may vary. Other mathematics courses are more advanced and more abstract and may demand more explaining and visualization. For example, geometry classes may require geometric objects properly drawn in the modules or in other online platforms. Advanced and abstract courses may require materials with more examples, better visualizations, and clearer explaining. Also, the prerequisite of these advanced and abstract courses are normally the basic ones. This hierarchical nature of mathematics makes it more difficult to teach because one topic build upon the other (Fhloinn & Fitzmaurice, 2021). The same authors provoked the question of whether all mathematics can be taught successfully in an online platform.

Based on these arguments, this study hypothesizes that the gravity of learning difficulties is more severe for students taking advanced and more abstract mathematics courses than students who are taking minor or basic courses. For this reason, one of the goals of this paper is to show whether the degree of seriousness of difficulties is higher among students enrolled in different levels of mathematics. In this study, "level" pertains to whether a course enrolled by a student is basic, advanced, or major. A basic course refers to a minor course such as Mathematics in the Modern World which is a combination of basic topics on patterns, sets, functions, and statistics. Advanced courses include Calculus, Differential Equations and other courses taken by students who are not mathematics majors. Major courses on the other hand are those who are taking courses with more abstract nature such as abstract algebra, number theory, real analysis, linear algebra, and modern geometry. These are courses that are additionally taken by mathematics majors on top of the advanced courses.

METHODS

This study is quantitative. Specifically, it is exploratory since the first goal is to identify the emerging students' difficulties in mathematics flexible learning (MFL) via a dimension-reduction analysis called Principal Component Analysis. It is also descriptive as it attempts to measure the magnitude of seriousness of these difficulties among the students involved in the study.

Participants

This study involved 273 students in one Philippine university who were enrolled in mathematics courses during the first semester of the school year 2021-2022. The decision of the sample size is based on the guideline set by Jolliffe (2002) stating that for principal component analysis, the minimum sample size is 200. The sample was further selected via cluster random sampling. Students' block section was used as the clustering variable. Cluster sampling was used since the list of block sections is available but not the list of students in the population (Singh & Masuku, 2014). Also, the sectioning performed by the university at the beginning of the semester was already random hence the students' block sections are natural clusters of the population.

Table 1 presents the demographic profile of the respondents. In terms of the classification of their residence, about half of them reside in rural areas while the other half in urban areas. Also, the only available device for the majority (55%) of the sample is a mobile phone. With regard the internet speed, an outstanding 67.03% declared that their connection is very slow. There were more students (53.11%) declared that they have advanced level of proficiency in using gadgets to access learning resources or use it during synchronous classes. When asked what time of the day they usually access their learning resources, 38% said "nighttime", another 38% of them mentioned that they do not follow a specific schedule while only 17.48% of them follow their class schedule. The sample respondents are further distributed according to the level of mathematics course they are enrolled at. Of the total sample, around 48% of students are enrolled in a basic mathematics course, 28.57% are enrolled in an advanced course while the remaining 23.43% are enrolled in major courses. These major courses are taken by students taking (a) Bachelor of Secondary Education major in Mathematics and (b) Bachelor of Science in Mathematics. Advanced mathematics courses on the other hand are taken by students enrolled in STEM programs such as engineering, chemistry, biology, environmental science, and food technology. The basic mathematics course is taken by all students as a minor.

Table 1. Demographic profile of the respondents

Demographic Profile	Categories	Frequency	%
Classification of residence	Rural	128	46.89
	Urban	145	53.11
Availability of devices	Mobile Phone Only	149	54.58
	Desktop/Laptop Only	6	2.20
	Desktop/Laptop with Mobile Phones	116	42.49
	No available device	2	0.73
Speed of internet connection	Fast	62	22.71

	Slow	28	10.26
	Very Slow	183	67.03
Level of mastery in using devices to access learning resources or attend synchronous classes	Beginner	60	21.98
	Proficient	68	24.91
	Advanced	145	53.11
Time of accessing Learning Materials	As long as the work is finished	4	1.47
	Early morning	15	5.49
	Night time	103	37.73
	Following class schedule	48	17.58
	No specific schedule	103	37.73
Level of Mathematics Course	Basic	131	47.99
	Advanced	78	28.57
	Major	64	23.43

Legend
Basic Course : Mathematics in the Modern World
Advanced Courses: Differential Calculus, Integral Calculus, Advanced Calculus, Differential Equations
Major Courses : Abstract Algebra, Number Theory, Linear Algebra, Real Analysis, Modern Geometry, Reasoning in Mathematics

Data Collection and Analysis

The Scale

Students' Difficulties in Mathematics Flexible Learning (SDMFL) is a researcher-made survey questionnaire. The construction of SDMFL is guided by (a) the literature review on the different difficulties encountered by students in their mathematics classes during the pandemic and (b) the result of the qualitative analyses of the data gathered from a separate inquiry of a group of students (n=100). This inquiry involves asking students to write an essay or a narrative regarding their learning difficulties they have experienced in their mathematics classes. All the difficulties derived from both this inquiry and the literature review were converted to item statements. These items were further subjected to content validity by selected experts. This process ensured that all items are easy to understand and appropriate for the purpose of the study. These items were subjected to another round of pilot testing involving thirty-six (36) students. Based on their responses, confusing items were revised, and suggestions were integrated. The final SDMLF survey questionnaire consists of 44 items reflecting students' difficulties in all possible areas during their mathematics flexible classes. A five-point Likert scale was additionally developed to measure the degree of seriousness of these difficulties: (1) not serious at all, (2) less serious, (3) moderately serious, (4) very serious, (5) extremely serious. The decision of the number of categories is based on the suggestions that the optimal number of categories of rating scales is seven plus or minus two (Miller, 1956) or exactly five (Jenkins & Taber, 1977; Lissitz & Green, 1975).

The 44-item SDMFL survey questionnaire was converted into a google form. Students included in the sample were first oriented regarding the purpose of the study and were given data privacy notices stating the confidentiality of information that will be gathered from them. After which, informed consent was secured. Only those who were willing to participate answered the research questionnaire. The data collected from this administration were analyzed using the statistical tools described below.

Principal Component Analysis (PCA)

PCA is the main statistical technique used in this study. PCA is a multivariate statistical method that is mainly used to reduce the dimensionality of a correlated and high dimensional dataset (Bro & Smilde, 2014). This procedure reduces and transforms many variables to fewer latent variables or factors while maintaining most of the information (Li et al., 2016). These orthogonal latent variables are otherwise called principal components (PCs) in PCA and are expressed as a linear combination of variables.

Let X be an *ixj* data matrix with *i* as the number of respondents (sample size) and *j* as the number of independent variable indicators (question items) X_j .In the original data, $i = 273$ and $j = 44$. The PCs Y_p are expressed as linear combinations of the variables as follows:

$$Y_1 = [X_1\ X_2\ \cdots\ X_j\ ][a_{11}\ a_{12}\ \vdots\ a_{1j}\ ] = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1j}X_j$$

$$Y_2 = [X_1\ X_2\ \cdots\ X_j\ ][a_{21}\ a_{22}\ \vdots\ a_{2j}\ ] = a_{21}X_1 + a_{22}X_2 + \cdots + a_{2j}X_j$$

$$\vdots$$

$$Y_p = [X_1\ X_2\ \cdots\ X_j\ ][a_{p1}\ a_{p2}\ \vdots\ a_{pj}\ ] = a_{p1}X_1 + a_{p2}X_2 + \cdots + a_{pj}X_j \qquad (1)$$

This computation allows the sum of variances of all PCs to equal the sum of the variances of the original variable indicators. The transformations above are collectively written as $Y = XA$. The row matrices A are called the eigenvectors associated with the correlation matrix of the original data.

The steps for the PCA computation are listed below:

1. Standardized the data set by converting each data point x_{ij} under the i^{th} observation and the j^{th} indicator variable to u_{ij} such that $u_{ij} = (x_{ij} - \underline{x_j})/s_{x_j}$ where $\underline{x_j}$ and s_{x_j} is the mean and standard deviation of the indicator x_j respectively.
2. Compute for the correlation coefficient matrix $R = [r_{qp}]$. Each of r_{qp} is the correlation coefficient between two indicator variables q and p is given by
$$r_{qp} = \frac{\Sigma_1^i\left[\left(p_i - \underline{p}\right)\left(q_i - \underline{q}\right)\right]}{\sqrt{\Sigma_1^i\left(p_i - \underline{p}\right)^2 \Sigma_1^i\left(q_i - \underline{q}\right)^2}}. \qquad (2)$$
3. Compute for the eigenvalues associated to the correlation matrix computed above. Given a non-zero vector v, if $Rv =; \lambda v \Rightarrow Rv - \lambda v = 0 \Longrightarrow (R - \lambda)v = 0$, λ is the eigenvalue associated to the eigenvector v of the matrix R.
4. Based on the eigenvalues, sort the eigenvectors in decreasing order.
5. Form a matrix of k eigenvectors with the largest eigenvalues.
6. Transform the original matrix into a k dimensional PCA subspace.

Descriptive Statistics

After the principal component analysis is conducted, descriptive tools are used to describe in general the respondents' ratings on these components. Specifically, the mean is computed to measure the degree of seriousness of students' difficulties in flexible mathematics learning. To provide a better picture of the data, standard deviation, the maximum, and the minimum values is reported as well. This will generally describe the spread of students' responses in each of the components.

Analysis of Variance

Finally, to compare the degree of seriousness of the identified difficulties, ANOVA is utilized. This will inferentially test whether at least one of the groups being compared is significantly different when students are grouped according to the level of mathematics course students are enrolled at. In cases where

ANOVA detects differences, a post-hoc test called Duncan's Multiple Range Test (DMRT) is further run to specify which of the groups are significantly different.

RESULTS AND DISCUSSION

This section presents the statistical results of the study. First, it shows the procedures conducted to identify the principal components extracted from the data. After the initial and final identification of the components, the overall rating of students in these components is presented. Also, comparisons of these difficulties according to the level of mathematics courses are provided.

Initial and Final PCA

During the initial principal component analysis, there were 9 components extracted. However, due to the presence of cross loading and low factor loadings, another reduction decision was made. Specifically, nine (9) items from the SDFML survey questionnaire were removed, leaving only thirty-five (35) items which were further subjected to the final PCA analysis with varimax (with Kaiser Normalization) as the rotation method (Schumacker & Lomax, 2010). For the final analysis, only components with eigenvalue greater than one are retained (Cattell, 1966; Kaiser, 1960). Before the final components are presented, other requirements and important statistical results for a PCA analysis are established. These include the measure for sampling adequacy, total and individual variance, scree plot, and factor loadings.

Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy and Bartlett's Test

The KMO value is 0.90. Since it is higher than 0.50, this indicates that the sample size equal to 273 is adequate for PCA. Moreover, the p-value for the Bartlett's Test of Sphericity is less than 0.01 (approx. chi-sq.=4671.53, df=528). This means that the correlation matrix is an identity matrix (Verma, 2012) suggesting that the use of PCA is suitable.

Eigenvalues, Individual, and Total Variance Explained

After rotation, there were seven components extracted. As shown in Table 2, the corresponding eigenvalues for these components range from 10.87 to 1.18. Collectively, these seven components account for 64.13% of the total variance explained. The first component with an individual variance of 16.89% captures the maximum variance in the data set. This is followed by component 2 explaining 10.37% of the total variance. This pattern continues downward to component 7, the component with the least amount of total variance explained.

Table 2. Eigenvalues, and Individual and Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loading			Rotation Sums of Squared Loading		
	Total	Var. (%)	Cum. (%)	Total	Var. (%)	Cum. (%)	Total	Var. (%)	Cum. (%)
1	10.87	31.06	31.06	10.87	31.06	31.06	5.91	16.89	16.89
2	3.47	9.92	40.98	3.47	9.92	40.98	3.63	10.37	27.26
3	2.35	6.71	47.70	2.35	6.71	47.70	2.98	8.52	35.78
4	1.83	5.22	52.92	1.83	5.22	52.92	2.90	8.27	44.06
5	1.63	4.67	57.58	1.63	4.67	57.58	2.70	7.70	51.76
6	1.23	3.50	61.08	1.23	3.50	61.08	2.62	7.48	59.24
7	1.18	3.38	64.46	1.18	3.38	64.46	1.83	5.22	64.46

The Scree Plot

Figure 1 presents the scree plot between the eigenvalues (y-axis) and the components(x-axis). This plot consistently suggests that seven components are to be retained as indicated by the number of components to the left of the “elbow” bend.

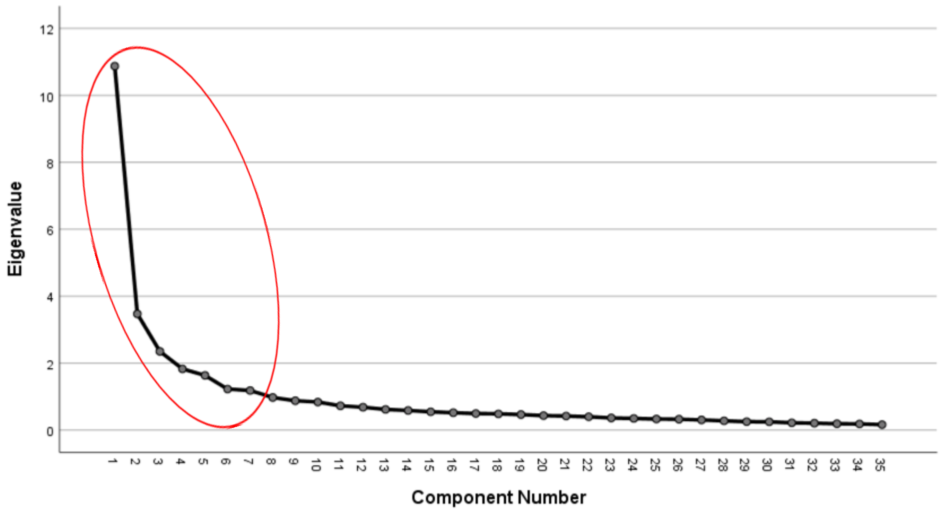

Figure 1. Scree Plot

Principal Components in Themes and Factor Loadings

Based on the statistical analysis, seven components were extracted. The factor loading of the variables (items) under each component is displayed in Table 3. The loadings are numerical values that range from -1 to 1 and represent the weights corresponding to the magnitude a variable is correlated to a component. Also take note that the factors were rotated (varimax) for more efficient results. The variables that are included are those with loading higher than 0.50. Awang (2014) suggested that for newly developed items, loadings must exceed 0.50. Of the 44 items of the SDMFL questionnaire, 9 items had loading that did not meet this criterion and hence were removed. In total, there are 35 items distributed across the seven components.

Based on the grouping of items, a qualitative analysis was conducted before a thematic name was carefully provided for each component. For example, the ten (10) items that load under component 1 contain the phrases “there are too few examples in the module”, “explanations in the module are not clear”, “modules lack information”, “instructions are not clear”, “I learn without the teacher”, “teacher does not provide real-time feedback”, etc., all describing the quality of learning materials and support provided by the teacher. Similarly, all five (5) items under component 2 relates to students struggles in time management and procrastination so that this component is named “struggles in time-management”. Moreover, five (5) items that load to component 3 consistently describes the inadequate internet connection and devices of students. All the three (3) items comprising component 4 points to difficulties in submitting the requirements on-time. Another set of items load to component 5, all relating to students’ low self-efficacy in learning mathematics and using technology while four (4) other items describing students’ health-related challenges belong to component 6. Finally, three (3) item statements comprised component 7, all relating to students’ difficulties in communicating with their teachers and peers online.

Table 3. Factor Loading of Variables on Each Component Extracted with Themes

Component and Theme	Item Statement	Loading
1. Inadequate Mathematics Learning Materials and Supports	Q24: The mathematics lessons are difficult to understand because there are too few examples provided in the modules.	0.75
	Q26: The mathematics lessons are difficult to understand because the explanations in the modules are not clear.	0.75
	Q25: The mathematics lessons are difficult to understand because modules lack information and require intensive research.	0.73
	Q27: The instructions provided in the mathematics modules are not clear.	0.69
	Q33: Mathematics is difficult because I learn it alone and without my teacher explaining.	0.68
	Q35: Mathematics is not feasible for online learning.	0.68
	Q28: I am confused about my mathematics lessons because different references from the internet do not agree.	0.66
	Q34: The mathematics teacher cannot give real-time feedback or answers to my queries/questions	0.64
	Q36: Mathematics is difficult to understand because there is no video lecture to support the learning modules.	0.63
	Q32: The mathematics teacher only provides learning packets/modules/ materials.	0.61
2. Struggles in Time Management	Q6: My time management is poor.	0.80
	Q12: I get distracted by other things (hobbies, etc.) and end up cramming my requirements.	0.77
	Q11: I procrastinate which results in unfinished and unsatisfactory output.	0.76
	Q7: I am not able to manage time schedules between learning and household chores.	0.71
	Q10: Scheduling my time for different courses/subjects is difficult.	0.67
3. Unstable Internet Connectivity and Inadequate Technology	Q4: My internet connection/signal is poor.	0.83
	Q5: My area or location does not have a stable internet connection/signal.	0.79
	Q1: I cannot afford the Internet or data connection I need.	0.66
	Q2: I cannot afford to buy gadgets like laptops, mobile phones, printers, etc.	0.62
	Q3: I have limited resources such as school and educational materials.	0.58
4. Difficulty in submitting requirements on time.	Q38: The mathematics teacher started the lessons late resulting in a shortage of time to learn and submit requirements.	0.82
	Q39: The mathematics teacher did not provide a study guide or learning guide.	0.77
	Q37: The mathematics teacher does not give sufficient time to prepare and finish my requirements.	0.75
5. Low Mathematics and Technological Self-Efficacy	Q42: I find online learning difficult because I am not knowledgeable in using the different gadgets.	0.73
	Q43: I am not well-versed with the different online learning platforms.	0.73
	Q40: Mathematics is difficult for me because I am a slow learner.	0.68
	Q41: I am not confident that I can understand the topics in Mathematics.	0.60
	Q44: I feel like I don't understand parts of my learning material.	0.55
6. Health-Related Challenges	Q19: I feel like my eyesight is getting poorer after using computers (and the like) for too long.	0.82
	Q18: I feel body pains if I stay out late studying or making requirements using computers.	0.81

	Q17: I feel unhealthy working with gadgets for a long time.	0.78
	Q16: I often lack sleep because of school requirements.	0.53
7. Difficulty Communicating Online	Q23: Communicating with my classmates is stressful.	0.82
	Q15: It is difficult to collaborate with my classmates online.	0.65
	Q22: Communicating with my teacher is stressful.	0.53

Overall, Degree of Seriousness of the Students’ Difficulties in Mathematics Flexible Learning

Presented in Table 4 are the principal components extracted from the PCA together with the corresponding mean degree of seriousness and its descriptive equivalent. To provide a better picture of the data, the standard deviation and the range of responses are provided. These values generally describe the spread of the students' responses in each component.

For all components excluding components 4 and 7, the degree of seriousness is moderate. However, the standard deviation and range of their responses suggest that there is some variability of the degree of seriousness of the difficulties. For instance, the degree of seriousness of inadequate mathematics learning materials and support varies from 2.67−0.75=1.92 (less serious) to 2.67+0.75=3.42 (very serious). This is supported by the range of raw responses which is 1.00 to 4.90. This means that while the mean summarizes the degree of seriousness of this particular component (difficulty) as moderate, other students indicated a lower or higher degree than moderate. The observation is similar for difficulties in time management, internet connection and technology, mathematics, and technological self-efficacy, and in health.

Table 4. Mean and Standard Deviation of the Degree of Seriousness of the Difficulties

Component	Mean	Descriptive Equivalent	Standard Deviation	Range
1. Inadequate Mathematics Learning Materials and Supports	2.67	Moderately Serious	0.75	1.00-4.90
2. Struggles in Time Management	2.85	Moderately Serious	0.80	1.00-5.00
3. Unstable Internet Connectivity and Inadequate Technology	2.81	Moderately Serious	0.69	1.00-4.60
4. Difficulty in submitting requirements on time	1.81	Less Serious	0.78	1.00-4.67
5. Low Mathematics and Technological Self-Efficacy	2.86	Moderately Serious	0.78	1.00-4.80
6. Health-Related Challenges	3.18	Moderately Serious	0.86	1.00-5.00
7. Difficulty Communicating Online	2.48	Less Serious	0.80	1.00-5.00

Legend

Scale	Descriptive Equivalent
1.00-1.79	Not Serious at All
1.80-2.59	Less Serious
2.60-3.39	Moderately Serious
3.40-4.19	Very Serious
4.20-5.00	Extremely Serious

The overall degree of seriousness for the two components reflecting students' difficulties in “submitting requirements on time”, and “communicating with classmates and teachers” is less. However again, it does not mean that all students have experienced the same degree of seriousness. The values of the standard deviation and range of responses indicate that some students have declared higher degrees of seriousness on these components.

Students' Difficulties Compared According to the Level of Mathematics Course

Table 5 presents the comparison of the degree of seriousness of students' difficulties according to whether a student is enrolled in a basic, advanced, or major mathematics course. This is done by inferentially testing the means via Analysis of Variance (ANOVA) to identify whether the degree of seriousness of the difficulties in at least one of the groups differ. In cases where ANOVA detects significantly different mean, a post-hoc test called Duncan's Multiple Range Test (DMRT) is further run. This will specify in a pairwise manner which means are significantly different and which are not.

Results reveal that at least one of the three groups is significantly different in the degree of seriousness in two difficulties namely (a) inadequate mathematics learning materials and supports, and (b) difficulty in submitting requirements on time. The post-hoc test conducted further revealed that students enrolled in advanced and major mathematics courses have indicated higher degree of seriousness for these difficulties. Meanwhile, the degree of seriousness of the remaining difficulties is uniform across the three groups.

Table 5. Degree of seriousness of the students' difficulties compared

Difficulty	Mean			F-value	P-value
	Basic	Advanced	Major		
1. Inadequate Mathematics Learning Materials and Supports	2.44^{b}	2.83^{a}	2.93^{a}	12.38**	0.00
2. Struggles in Time Management	2.82	3.07	2.65	1.11^{ns}	0.10
3. Unstable Internet Connectivity and Inadequate Technology	2.78	2.79	2.88	0.52^{ns}	0.60
4. Difficulty in submitting requirements on time	1.61^{b}	1.91^{a}	1.99^{a}	6.81**	0.00
5. Low Mathematics and Technological Self-Efficacy	2.84	3.00	2.74	2.02^{ns}	0.14
6. Health-Related Challenges	3.14	3.32	3.11	1.48^{ns}	0.23
7. Difficulty Communicating Online	2.42	2.65	2.41	2.41^{ns}	0.09

Note. ns p>0.05, **p<0.01, means sharing the same letter are not significantly different

This section presents and gives meaning to the seven principal components extracted earlier. These components represent the trends and serve as summary indices of the important information derived in the sample data. In the context of this study, the components are the students' difficulties in Mathematics Flexible Learning in a nutshell. Having a clear picture of these difficulties allows one to provide deeper understanding and stronger recommendations after. The groupings will also reflect which indicator variables are related to each other. This section also discusses the results on the overall degree of seriousness of the difficulties as well as the result on the comparison of these difficulties according to level of mathematics course.

Principal Components of Students' Difficulties in Mathematics Flexible Learning

Component 1: Inadequate Mathematics Learning Materials and Supports

The first component is a measure of students' difficulties because of inadequate mathematics learning materials and support. As provided in Table 3, the variables (indicators) are those that describe students' difficult learning experiences due to poor quality of materials sent by the teacher or insufficient learning support given to them. Specifically, the quality of materials (modules) was deemed poor because there were too few examples given to support the topic, the explanations are ill-written, it lacks information which in turn requires students to conduct intensive research, and unclear instructions. In terms of learning support, mathematics learning was difficult because the teacher is unable to provide real-time feedback and additional materials such as video lectures.

This result may be attributed to the fact that the migration to flexible learning was unplanned. This means that teachers did not have enough time or appropriate training to make materials that effectively addresses the needs of students in online learning. Courses such as Geometry, Algebra, and Calculus have high visualization characteristics and need elaborate and time-consuming preparations because encoding mathematical objects and symbols require time and some digital proficiency. These courses may also require more examples to facilitate students' learning. This was apparent in a recent study conducted by Yohannes et al. (2021) where most of the teachers reported that geometry learning media preparation is time-consuming, algebraic manipulation and trigonometric charts required more examples, and preparation of calculus and algebra materials was complex. In another study, it was shown that tertiary math lecturers who were used to face-to-face teaching experienced difficulties with online learning (Irfan et al., 2020). They further mentioned that interaction with students became limited and writing mathematical symbols was a struggle. Similarly, there was a difficulty for teachers to communicate mathematical ideas during live sessions and that classroom discussions are insufficient and unproductive (Akar & Erden, 2021). They added that the interactive materials become restricted during online classes. For example, the teacher cannot fully monitor and be able to provide immediate feedback to students doing construction tasks in their geometry class. In another survey among mathematics teachers during online classes, they mentioned that integrating technology into their pedagogical strategy requires practice (Cao et al., 2021).

Component 2: Struggles in Time Management

Another factor that made mathematics learning even more difficult is poor time management. Procrastination, distractions, and household chores result in students' failure to work on their tasks and requirements. Time management is important in higher education as it influences how time is used to complete academic tasks accordingly. Because the students are at the comfort of their homes, following schedules may be challenging especially that full supervision of teachers is cut off. Aside from the household chores and hobbies, students may be easily tempted to do unrelated activities on the internet such as involvement in social media and entertainment. A study conducted by Hermanto et al. (2021) revealed that learning at home did not help many students manage their time better as most of them have social media accounts. The presence of gadgets such as mobile phones may disrupt learning by doing non-classroom activities (McCoy, 2016).

Component 3: Unstable Internet Connectivity and Inadequate Technology

Unstable internet connection is the third component of students' difficulty. Students have zero to poor internet connection which in turn prevents them from accessing learning materials or attending synchronous classes. Aside from connectivity problems, students have limited gadgets such as mobile phones and laptops. As was presented at the earlier parts of this paper, this is to be expected since the Philippines is a third world country where the digital divide is prominent. This result is consistent with the results of similar studies stating that unstable internet is a difficulty encountered in remote learning (Bao, 2020; Baticulon et al., 2021; Henaku, 2020). Poor internet is a common problem in developing countries such as the Philippines (Rotas & Cahapay, 2020). Moreover, multiple device ownership during online learning offers many advantages. For example, multiple devices allow one to view in multiple screens (Pynos, 2016) and create seamless connectivity thus keeping the continuity of the learning experience (Milrad et al., 2013). Unfortunately, this is not the case for students in this study.

Component 4: Difficulty in Submitting Requirements on Time

This component is the amalgamation of variables (indicators) pertaining to the inability of student to submit requirements on time because either the teacher mismanages his/her time schedule, did not provide a study guide to keep them in check of submission schedules, or did not simply provide enough time for students to prepare and finish their requirements. There could be two possible reasons for this. First, it is possible that teachers are unable to adjust the amount of time given to complete a mathematical task. The barriers described in components 2 and 3 shows that the pacing of the teaching-learning process during mathematics flexible learning is much slower than in the traditional face-to-face classes. This is because learning materials, support, internet connection, and technology are involved in the delivery of instructions. Consequently, the amount of time for students to complete a task is expected to be longer. Second, this could be the effect of students' difficulties discussed in component 2. Inability to submit requirements on time is reasonably a result of poor time management. Unfortunately, the literature is extremely scarce of studies that investigated time allocations and other practices related to online mathematics assessments.

Component 5: Low Mathematics and Technological Self-Efficacy

Mathematics self-efficacy is a self-perception and confidence of being successful in a mathematics task (Ferla et al., 2015). Technological self-efficacy on the other hand describes students' confidence to use gadgets and navigate the different online platforms. Accordingly, the four core elements of self-efficacy are (1) performance accomplishments, (2) vicarious experience, (3) verbal persuasion, and (4) physiological states (Bandura, 1997). Briefly, performance accomplishment is based on the learners' own previous successes, vicarious experiences is based on other learners' successes observed, verbal persuasion is based on the feedback and encouragement of a persuader, while physiological state refers to whether a person is in an aversive arousal. These sources are also applicable to online learners (Alqurashi, 2016). Bates and Khasawneh (2007) added that in online learning, self-efficacy is influenced by (1) previous success, (2) pre-course training, (3) instructor's feedback, (3) online learning technology anxiety.

These sources may as well explain why students have low self-efficacy. Component 1 describes the problem of real-time feedback from the teacher. This in turn affects the awareness and monitoring not only of one's performance but of others as well. If the communication is limited in the first place, it follows that feedback and encouragement is limited. Furthermore, because the migration to flexible learning is unplanned, there were no preparations such as training and workshops on the use of technology given to students. Students are left to discover and explore this technology as their class progresses.

Component 6: Health-Related Challenges

This component encompasses students' health-related difficulties experienced during the flexible learning. Specifically, students claim that their eyesight has suffered due to long exposure to gadgets. Body pains and lack of sleep are results of doing requirements in the computer for a long time. Similar results are evident in a study conducted by Rotas and Cahapay (2020) where university students are concerned about their physical health being compromised because they spent too much time doing class activities and were engaged too little in physical activities. Moreover, students' individual barriers to online learning include physical health (Baticulon et al., 2021).

Component 7: Difficulty Communicating Online

The final component describes the students' difficulties in communication and collaborating with both of their teachers and classmates online. It is to be noted that success depends on the quality of two-way communication between students and teachers, and among students themselves. In a study conducted by Cao et al., (2021), teacher-student interaction was a problem because in online classes, verbal and non-verbal communication is challenging.

Overall Degree of Seriousness of Students Difficulties in Mathematics in the Purview of Flexible Learning

As presented in Table 4, students' ratings on the degree of seriousness of the difficulties are spread across the measuring scale. This means that students have experienced the difficulties in varying levels. These variations may stem from students' diverse learning environments and opportunities. As evidence by the student's demographic profile presented in Table 1, almost half reside in rural areas while the other half in urban areas. Some owns multiple devices while others use their mobile phones only. Moreover, their level of proficiency to use these gadgets in accessing learning resources or attending synchronous classes vary from "beginning" to "advanced" while the speed of internet varies from fast to very slow.

Notable Observations on the Comparison of the Degree of Seriousness of Students Difficulties According to the Level of Mathematics Course

Based on the results presented earlier, the degree of seriousness of "inadequate learning materials and support" among students enrolled in advanced and major courses is higher than with students enrolled in basic mathematics courses. This reflects the fact that advanced and more abstract mathematics courses require a higher level of visualization during the teaching-learning process. This in turn requires some knowledge of media platforms and tools appropriate for communicating online as well as some digital proficiency to translate mathematical topics to self-sufficient learning materials (e.g., modules). Also, advanced and abstract courses are more difficult to communicate because topics are more complex and therefore require more elaborate explanation and examples especially in a case where technology is insufficient, and time is a constraint. Many authors have in fact agreed that depending on the nature of mathematics, the way it is taught and the technological support that aide teachers should be reconsidered (Artigue, 2010; Freiman et al., 2017; Pierce & Ball, 2009).

It also appears that students enrolled in advanced and major courses have a higher level of difficulty in terms of submitting their requirements on time. The amount of time needed to finish a task is reasonably dependent on whether the student has sufficiently understood a topic either through synchronous or asynchronous learning. If the teaching-learning process is hampered and understanding slows down because communicating mathematical content is a struggle between the teacher and students, it follows that students are unable to provide the output that is expected of them. Teachers' inexperience with online learning may also have accounted for this difficulty. It is possible that the time given to finish a task is appropriate to traditional face-to-face classes and not for online or flexible classes. This means that teachers are unable to adjust assessment practices so that it is appropriate and practical for flexible learning.

CONCLUSION

The seven components derived via Principal Component Analysis highlights the emerging difficulties of students in mathematics in the purview of flexible learning. The first component is attributed to difficulties due to inadequate learning materials and insufficient learning support provided by the teacher. These difficulties appear to have impacted the students' understanding of mathematical contents. Four other components are student related. These include students' inability to manage time, difficulty submitting requirements on time, low mathematics and technological self-efficacy, and compromised health. The remaining two components namely "inadequate internet connectivity and devices" and "difficulty communicating online" are technology related. These difficulties appear to be the by-product of the abrupt migration to flexible learning. Moreover, these difficulties may have been intensified by the nature of mathematics. That is, because mathematics is a language of symbols and notations that represent advanced, complex, and abstract ideas, communicating them online is a massive challenge. This is further supported by the results showing that students enrolled in advanced and major courses have experienced higher levels of difficulty particularly during the reception of contents and assessment.

The seven-component students' difficulties may serve as a model for teachers, students, and administrators towards attaining a more successful mathematics classes conducted in a flexible mode. On the part of the teachers, improving the communication and delivery of the learning content through trainings and workshops may be prioritized. On the part of the students, they may be reminded of the importance of time management and strategies to manage disruptions during flexible classes. Relevant programs like seminars on self-learning strategies and maintaining a healthy lifestyle may be initiated.

Finally, the difficulties identified are possibly overlapping and intertwined. For future studies, one may investigate the relationship between and among these difficulties to provide evidence-based results on how they interact with each other. By investing in these suggestions, not only do we improve the teaching-learning process at present but also establish what is needed towards a sustainable online or flexible academic program that the university may offer long after the pandemic is over.

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