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| RESEARCH ARTICLE

Mathematical Smartphone Use and Achievement in University Linear Algebra

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| ABSTRACT
This article reports a reanalysis of smartphone use among 100 first-year Statistics students taking university linear algebra. The students were enrolled in three existing course sections. In two sections (n = 67), instructors promoted mathematical applications for selected course activities; the third section (n = 33) provides a descriptive comparison. We worked from the original item-level records rather than from previously computed totals. During that audit, we reconstructed the questionnaire scores, corrected the opposite response direction used in the final mathematical-use items, and identified a faulty spreadsheet aggregate that had counted several domain subtotals twice. Seven mathematical activities were asked at both measurement occasions. Their mean frequency scores rose by 4.45 points in Section 1, 8.48 in Section 2, and 3.97 in Section 3. Since instructional condition and course section were not separable in this design, these figures describe the observed trajectories and are not estimates of an intervention effect. Final course grades differed markedly among sections. Internal consistency of the reconstructed domains ranged from Cronbach's alpha = .336 to .901. Pearson correlations with final grade ranged from -.241 to -.039; confidence intervals and Spearman coefficients are reported to show the uncertainty and robustness of these estimates. The findings indicate that smartphone ownership, general phone activity, mathematical use, and academic achievement should be treated as distinct features of students' experience.

| KEYWORDS
Academic achievement; linear algebra; mathematics education; mobile learning; smartphone use; technology integration

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1. Introduction

For most university students, the smartphone is no longer a new classroom technology. It is an ordinary personal device that accompanies them throughout the day. Students' everyday experience with smartphones does not necessarily extend to their use as mathematical tools. A smartphone can enter a student's routine in several ways. For this study, the distinction lies in the task being performed rather than in the device itself.

This distinction becomes particularly noticeable in linear algebra. Digital applications can carry out many of the computations encountered in an introductory course: they can solve systems of equations, calculate determinants and inverses, perform matrix operations, and display results almost immediately. Such functions may be useful, especially when lengthy calculations would otherwise occupy much of the class. At the same time, obtaining a numerical or symbolic answer is not the same as understanding the mathematical object or procedure that produced it. The educational role of the application depends on the task in which it is used and on what students are expected to do with the result.

The present study grew out of an Applied Linear Algebra for Statistics I course in which students already had extensive access to smartphones. Mathematical and educational applications were promoted in two existing course sections, while a third section followed the course without that same organized promotion. Questionnaires administered during the academic period recorded several kinds of smartphone activity, including a set of uses directly related to mathematics. Final course grades were also

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available. Because the sections were already formed and the instructional condition coincided with section membership, the data do not constitute a randomized experiment. The comparison among sections is consequently descriptive rather than causal.

Before proceeding with the analysis, we returned to the original student-level responses and compared them with the two questionnaires. This check revealed problems that were not apparent in the previously computed totals. Most notably, the response scale for the mathematical items in the second questionnaire ran in the reverse direction from the scale used at the first measurement. We also found that the spreadsheet variable intended to summarize overall use included both individual items and some of their corresponding subtotals. As a result, part of the information was counted more than once. We did not use that aggregate in the present analysis. Instead, each score was rebuilt directly from the relevant questionnaire items after the response scales had been put in a common direction.

The revised dataset is used to examine three related, but distinct, aspects of the students' experience. We first describe the ways in which smartphones were used for mathematical work. We then follow the seven activities that appeared in both questionnaires and report how their frequency changed within each of the three course sections. Finally, we examine the relationship between the reconstructed use measures and students' final grades. We consider these questions separately because having a smartphone, using it regularly for mathematics, and performing well in the course are not equivalent outcomes.

Our purpose is descriptive rather than causal. The data can show what was reported by this cohort and how those responses differed across measurement occasions, but they cannot determine whether encouraging the use of mathematical applications improved achievement. Reported frequency indicates how often students turned to an application, not what they learned from doing so. We consequently use these responses as records of self-reported practice and make no inference about mathematical understanding from frequency alone. A separate concern emerged when the original scores were checked. Seemingly minor decisions made while preparing questionnaire data can have substantive consequences: reversing a scale changes the meaning of high and low values, while the composition of a summary score determines which responses contribute to the quantity eventually analyzed.

2. Literature Review

The literature on smartphone use in higher education is difficult to read as a single body of evidence because the underlying studies often refer to quite different forms of activity. Amez and Baert (2020) show how strongly the definition and measurement of phone use vary across this literature. Previous studies have reported different relationships between mobile technology and academic performance (Kates et al., 2018; Sung et al., 2016). In mathematics education, access to a digital tool should also be distinguished from its use as a mathematical instrument (Artigue, 2002; Trouche, 2004). This distinction is relevant in linear algebra, where computational work is closely connected with conceptual and formal understanding (Dorier, 2000). Software can solve a system or perform matrix calculations quickly; a record of frequent use, however, does not reveal how the student understands the calculation or interprets its result. For that reason, our analysis treats general smartphone activity, mathematics-specific use, and final course performance as distinct quantities.

3. Methodology

3.1 Research Design and Participants

We examined records from 100 first-year Statistics students enrolled in Applied Linear Algebra for Statistics I at a Mexican public university between August 2019 and January 2020. The study was quantitative in approach and descriptive-correlational in design. We analyzed the original questionnaire responses at the student level together with the corresponding final course grades.

The three course sections were already in place when the study was conducted; students were not allocated to groups for research purposes. Mathematical and educational smartphone applications were explicitly promoted in two sections (67 students in total); the third section contained 33 students and served as a comparison section. Because promotion status coincided with section membership, section and instructional condition cannot be separated statistically. We therefore describe the observed section trajectories without treating them as independent replications of an intervention.

3.2 Instrument

The first questionnaire contained items on communication (5), entertainment (12), sports (2), health (5), education (8), and mathematical smartphone use (7). Responses used five frequency categories. The mathematical items asked about simple and scientific calculators, algebraic operations, graphing, differentiation/integration, equations and inequalities, and matrix operations. The second questionnaire contained 18 mathematical-use items. It retained the seven comparable areas and added tasks specific to the linear algebra course, including systems of equations, determinants, transposes, inverses, matrix factorization, Gauss-Jordan elimination, the adjugate matrix, and dot and cross products.

We audited the item-level database before carrying out the analyses. In the first questionnaire, larger values indicated more frequent use (1 = never, 5 = always). The mathematical items in the second questionnaire had been stored in the reverse direction, so we recoded them before comparing measurement occasions or constructing final-use scores. Three zero values fell outside the permitted response range and were treated as missing. We then rebuilt each domain score from its component items. The spreadsheet also contained an aggregate variable labelled 'Uso'; inspection of its formula showed that several subtotals had been counted twice. We excluded that variable and constructed the general non-mathematical-use score directly from the 32 relevant items.

3.3 Academic Achievement and Statistical Analysis

Final course grade was used as the measure of academic achievement (M = 6.27, SD = 2.61). Descriptive statistics were calculated for the full sample and for each section. Longitudinal analyses used only the seven mathematical-use items that appeared in both questionnaires. Pearson correlations with final grade are reported with the number of valid cases and Fisher 95% confidence intervals; Spearman correlations provide a sensitivity check. Reliability was estimated separately for each reconstructed domain. For the two-item Sports score, we also examined the inter-item Pearson correlation (r = .466), since alpha is of limited value for a two-item composite.

3.4 Ethical Considerations

Both questionnaires told students that the information collected would be handled confidentially and used for research. All participants gave informed consent to take part. The analyses in this article use aggregate results and contain no names or other direct identifiers. The surviving study records do not include an institutional ethics-committee approval number, so no approval reference number is reported.

4. Results

4.1 Smartphone Access and General Use

Every participant owned a smartphone, and 75% reported using one during linear algebra classes. Messaging dominated general use: 84% said they always used instant messaging. Internet access was also nearly universal, with 94% reporting mobile Internet use. These figures describe a cohort for whom smartphone access itself was not a meaningful source of variation.

Table 1. Selected Indicators of Smartphone Access and General Use

Indicator	Result
Smartphone ownership	100%
Smartphone use during linear algebra classes	75%
Instant messaging – always	84%
Information searching – always/almost always	94%
Reading files – always/almost always	74%
Apps perceived as useful for mathematical problems	80%

4.2 Mathematical Smartphone Use

At baseline, smartphone use for matrix operations was uncommon: 50% of students reported never using one for this purpose and 26% almost never. For the seven mathematical activities measured at both occasions, 97 students had complete paired data after the final responses were recoded to a common direction. The mean score increased from 17.72 (SD = 5.25) to 23.30 (SD = 4.27), a change of 5.58 points (95% CI [4.05, 7.11]); the corresponding increases were 4.45, 8.48, and 3.97 points in Sections 1, 2, and 3, respectively. These values describe section trajectories, not intervention effects, because instructional condition coincided with section and only three sections were observed. Final-only items showed frequent smartphone use for Gauss-Jordan elimination (64%), matrix factorization (58%), the adjugate matrix (59%), the dot product (78%), and the cross product (83%); these percentages describe end-of-semester practice and cannot be interpreted as pre-post changes.

Table 2. Selected End-of-Semester Mathematical Smartphone Activities

Activity	Almost always/Always
Matrix factorization	58%
Gauss-Jordan elimination	64%
Adjugate matrix	59%
Dot product	78%
Cross product	83%

Table 3. Comparable Seven-Item Mathematical-Use Scores by Section

Section	Paired n	Pre M (SD)	Post M (SD)	Mean change	95% CI change
1 – promotion	33	17.61 (5.71)	22.06 (3.37)	+4.45	[1.73, 7.18]
2 – promotion	31	15.42 (4.10)	23.90 (4.09)	+8.48	[6.00, 10.97]
3 – comparison	33	20.00 (4.89)	23.97 (5.03)	+3.97	[1.25, 6.69]

Note. Final-wave items were reverse-coded before summation so that higher scores represent more frequent use at both time points. Section-level changes are descriptive; instructional condition was assigned at the section level.

Table 4. Internal Consistency of Reconstructed Scores

Score	Items	Complete n	Cronbach's alpha
Communication	5	99	.336
Entertainment	12	97	.647
Sports	2	100	.620
Health	5	100	.644
Educational use	8	100	.781
Mathematics – initial	7	100	.809
Mathematics – final	18	94	.901

Note. The Communication composite showed low internal consistency and should not be interpreted as a homogeneous psychometric scale. The Sports composite contains only two items; its inter-item correlation was r = .466, and its alpha should therefore be interpreted cautiously.

4.3 Smartphone Use and Academic Achievement

The original spreadsheet aggregate was excluded for the scoring reason described above. The reconstructed 32-item general non-mathematical-use score had M = 89.91 (SD = 12.61; n = 96) and correlated negatively with final grade (r = -.241, 95% CI [-.421, -.043]). Across domains, Pearson coefficients ranged from -.241 to -.039. Several intervals included zero and were wide enough to accommodate associations of nontrivial magnitude, so the estimates should be read with their uncertainty rather than classified simply as 'small' or 'null.'

Table 5. Correlations Between Reconstructed Smartphone-Use Scores and Final Course Grade

Reconstructed score	n	Pearson r [95% CI]	Spearman rho
Communication	99	-.080 [-.274, .119]	-.169
Entertainment	97	-.231 [-.411, -.033]	-.233
Sports	100	-.148 [-.334, .050]	-.154
Health	100	-.190 [-.373, .006]	-.235
Educational use	100	-.069 [-.262, .129]	-.069
Mathematics – initial	100	-.150 [-.336, .048]	-.212
Mathematics – final (recoded)	94	-.039 [-.240, .165]	-.124
General non-mathematical use	96	-.241 [-.421, -.043]	-.240

Spearman estimates were broadly consistent with the Pearson results. Corrected final mathematical use showed little linear association with final grade (r = -.039, n = 94, 95% CI [-.240, .165]; Spearman rho = -.124). Entertainment and general non-mathematical use had the largest negative Pearson coefficients. Grades also differed sharply by section: M = 7.31 (SD = 1.89) in Section 1, 7.38 (SD = 1.56) in Section 2, and 4.09 (SD = 2.75) in Section 3. This heterogeneity limits the interpretation of pooled associations.

5. Discussion

All 100 students owned a smartphone, leaving no meaningful variation in access within the sample. Their academic use of the device was another matter. At the first measurement, several mathematical tasks were seldom carried out by phone, even though every participant already had the necessary hardware. Ownership, in this cohort, tells us that the technology was available; it does not tell us how far the phone had become part of students' mathematical work. Matrix operations are the clearest example: 50% of the students reported never using a smartphone for this purpose and another 26% reported doing so almost never. The device was already present in students' lives, but it had not yet become a regular tool for this part of their mathematics work.

By the end of the semester, the seven activities measured on both questionnaires were reported more frequently in all three sections. The average increase was 4.45 points in Section 1, 8.48 in Section 2, and 3.97 in Section 3. The larger change in Section

2 is noteworthy as a description of that group, but the design does not allow us to assign the difference to the promotion of applications. The sections existed before the study, promotion status was attached to section rather than to individual students, and only one section served as a comparison. In addition, Section 3 began with a higher mean score on the common mathematical-use items. These features leave several plausible explanations open, including differences in the students, instruction, assessment, and starting level.

By the end of the semester, students were using smartphones for mathematical tasks that extended well beyond the activities captured at the first measurement. Frequent use was reported for Gauss-Jordan elimination, matrix factorization, the adjugate matrix, and the dot and cross products. Several of these tasks, however, had no corresponding baseline item. Their final frequencies cannot therefore be interpreted as evidence of change over time. They describe the range of mathematical work in which smartphones appeared near the end of the course.

Associations with final grade varied according to the type of smartphone use being measured. Once the domain scores had been reconstructed from the item-level responses, general non-mathematical use correlated negatively with final grade ($r = -.241$, 95% CI [-.421, -.043]); entertainment yielded a comparable negative estimate. Corrected final mathematical use, by comparison, was close to unrelated to grade in the Pearson analysis ($r = -.039$, 95% CI [-.240, .165]). Spearman coefficients did not materially alter this pattern. The results therefore resist a uniform interpretation of smartphone use as either favorable or unfavorable to course performance. Some estimates are also too imprecise for strong conclusions, as indicated by their confidence intervals.

Frequency of mathematical use should also be kept separate from mathematical understanding. The questionnaire can identify whether a student turned to an application for a particular task, but it cannot reveal how that student interpreted the output or understood the procedure. Computing an inverse or reducing a matrix with software, for example, may occur without an explanation of the operations involved. Work on instrumental genesis offers a useful way to state what these data can and cannot show (Artigue, 2002; Trouche, 2004). Using a digital resource is only one part of the process through which that resource becomes a mathematical instrument for the learner. Our questionnaire identifies reported use during mathematical tasks. It does not observe the schemes students developed while working with the application, and the analysis makes no claim that it does.

Frequency alone also leaves the classroom context largely invisible. In the account of instrumental orchestration given by Drijvers et al. (2010), mathematical work with technology depends partly on how the teacher coordinates the tool, the task, and the surrounding interaction. Two students may report using a determinant application equally often while engaging with it in quite different ways.

The final questionnaire contained reversed coding, three responses were recorded as zero despite zero lying outside the permitted scale, and some observations were missing. In addition, the original spreadsheet aggregate counted several domain scores twice. The Communication composite showed low internal consistency and should be interpreted accordingly. The data were collected in 2019-2020; patterns of smartphone use among current students may no longer match those observed in this cohort. Taken together, these features restrict the analysis to a descriptive and correlational account of this cohort; they do not support an estimate of the effectiveness of smartphone applications.

6. Conclusion

The reanalysis does not yield a simple verdict on smartphones in linear algebra, nor was the study designed to do so. What emerges instead is a distinction between access and mathematical practice. Smartphone ownership was universal in the sample, but mathematical use was initially uneven. For the seven activities that could be matched across the two questionnaires, reported frequency increased over the semester in each of the three course sections.

Those within-section changes should not be interpreted as estimates of an instructional effect. The sections were already constituted when the study took place, and the promotion of mathematical applications coincided with section membership rather than with an independently assigned treatment. Baseline use also differed across sections, as did final course grades. The data therefore support a description of three observed trajectories, but they do not identify the promotion of applications as the cause of the differences among them.

The association with achievement likewise depended on what was counted as smartphone use. The reconstructed general non-mathematical score was negatively associated with final grade ($r = -.241$, 95% CI [-.421, -.043]), whereas corrected final mathematical use produced an estimate close to zero ($r = -.039$, 95% CI [-.240, .165]). These estimates describe separate forms of smartphone activity and are best interpreted on their own terms. Treating them as a single indicator would obscure the difference observed in the data. The mathematical-use score has a similarly specific meaning: it records students' reported frequency of application use. It was not designed to assess whether they could explain, justify, or otherwise demonstrate understanding of the mathematical procedures involved.

Rechecking the source data also changed how the longitudinal scores were constructed. The mathematical items on the final questionnaire used the response scale in the opposite direction from the corresponding baseline items. We therefore reversed those final responses before comparing the two measurement occasions, so that larger values had the same interpretation throughout the analysis. We also excluded the spreadsheet aggregate after finding that several subtotals had been counted twice. The resulting scores therefore rest on the individual questionnaire items rather than on the faulty precomputed total. Future studies of this kind should make scoring rules explicit from the outset, keep response direction consistent across measurement occasions, and retain item-level records that allow composite scores to be checked.

A stronger design would also include more independent course sections and direct measures of mathematical understanding. That would make it possible to separate section effects from instructional conditions and to examine not only how often students use an application, but what mathematical work they perform with it. In linear algebra, that distinction is likely to matter more than the mere presence of a smartphone in the classroom.

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