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ORIGINAL PAPER

A national study on the teaching of statistics by Mexican college lecturers

Ana L. Gómez-Blancarte[1] · José G. Rivera-Pérez[2] · Lucía Zapata-Cardona[3]

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Abstract

Research in statistics education has contributed to the reform of statistics curricula in many countries. It has been argued that statistics has its own ways of thinking, so statistics education needs to be approached differently from mathematics. Learning how lecturers teach and assess statistics in Mexico provides the knowledge required to review their current practices and take actions to improve the teaching and learning. In this context, we report on a national research project to characterize the teaching and assessment of statistics among Mexican college lecturers. We designed a 76-item survey based on six recommendations from the Guidelines for Assessment and Instruction in Statistics Education (GAISE): teach statistical thinking; focus on conceptual understanding; integrate real data with a context and purpose; foster active learning; use technology to explore concepts and analyze data; and use assessments to examine and evaluate student learning. To validate the survey, exploratory and confirmatory factor analyses were applied to the responses of 750 lecturers. We explore how well the lecturers' teaching and assessment practices aligned with the GAISE recommendations and examine the academic variables associated with these practices. Our findings show the need to offer lecturers statistical learning experiences to improve their use of technology and diversify their assessment activities to fulfill the GAISE recommendations better. Experience in data analysis, involving statistical and technological knowledge, was one of the variables with the highest correlations. However, these were weak associations with the lecturers' teaching and assessment practices. Further research is needed to explore these associations more deeply.

Keywords Statistics teaching · College statistics · Statistical thinking · Assessment · Technology

1 Introduction

The evolution of statistics curricula at the tertiary level (Zieffler et al., 2018), social demands, and technological advances all led us to evaluate and reflect on distinct proposals to guide statistics teaching and modify curricular approaches in this discipline (Pfannkuch, 2018). Studying the teaching and assessment of statistics at the college level is essential to identify the strengths and weaknesses of these processes and undertake actions that lead to improvements in the teaching/learning of the discipline (Batanero, 2019).

✉ L. Zapata-Cardona
lucia.zapata1@udea.edu.co

[1] Instituto Politécnico Nacional, Ciudad de México, Mexico

[2] Universidad Autónoma de Tamaulipas, Tampico, Mexico

[3] Universidad de Antioquia, Medellín, Colombia

The growth of statistical education has brought to light several challenges at the college level, including selecting appropriate statistical content (what to teach) and a suitable approach to teaching that content (how to teach), using that teaching to address real-world professional problems (why to teach), and preparing faculty (Hernández González et al., 2013; Wilks, 2006). Numerous proposals for teaching statistics at university have been offered systematically to overcome these challenges (e.g., Aliaga et al., 2005; ASA GAISE College Report Revision Committee, 2016; Bargagliotti et al., 2020; Gal & Garfield, 1997). The Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Reports 2005 (Aliaga et al., 2005) and 2016 (ASA GAISE College Report Revision Committee, 2016 [hereinafter GAISE College Report]) propose desired learning goals for students in introductory statistics courses. The most recent GAISE College Report offers six recommendations on what to teach and how to teach to achieve those goals: 1) *teach statistical thinking*; 2) *focus on con-*

ceptual understanding; 3) *integrate real data with a context and purpose*; 4) *foster active learning*; 5) *use technology to explore concepts and analyze data*; and 6) *use assessments to improve and evaluate student learning*.

While those proposals are relevant and logical for meeting the needs of modern society –such as preparing students to think statistically– further study is needed to determine how they are integrated into the teaching of statistics. In the United States, the GAISE recommendations (GRs) have served as a benchmark for course delivery by statistics lecturers (Zieffler et al., 2018), for shaping the professional development of lecturers in introductory high school and college statistics courses (Erhardt & Lim, 2020; Garfield & Everson, 2009), and for assessing how well statistics textbooks (Dunn et al., 2017) and lecturers' teaching and assessment practices (Fry et al., 2014; Hassad, 2011; Legacy et al., 2024; Zieffler et al., 2012) align with them.

In distinct contexts in Mexico, studies have explored the fulfilment of the eight statistical learning goals posited by Gal and Garfield (1997). They have reported that lecturers focus more on learning goals related to teaching methods and techniques than on developing statistical thinking (Cruz L. & Ojeda R., 2016); students concur that their courses stress goals related to "doing" more than "thinking" (Cruz López & Ojeda Ramírez, 2018). Indeed, around 20% of the 410 statistics syllabi of introductory statistics courses reviewed deemed those learning goals acceptable, as most emphasize data processing ("know-how") instead of statistical thinking, neglect the understanding of crucial processes for conducting statistical research ("knowing how to think"; e.g., posing research questions, discussing statistical results), and omit key concepts, such as variation (Cruz López & Ojeda Ramírez, 2021).

Pinto Sosa (2020) reported on the challenges that the teaching of statistics teaching faces at the college level from a curricular approach (syllabi and textbooks). He coincides with Cruz López and Ojeda Ramírez's (2021) results about curricular materials where content and exercises predominate with few opportunities to understand the usefulness of statistics for solving current social problems. Another study in Mexico reported that statistics courses generate more failing grades in accounting and administration programs. Students in that analysis indicated that poor knowledge of technological tools and their lecturers' traditional teaching and evaluation methods were among the causes of failure (Velázquez Pérez et al., 2014). Thus, as Pinto Sosa et al. (2007) affirm, we must identify the characteristics of lecturers who teach statistics courses, explore their academic needs, and evaluate their teaching and assessment practices.

Among other ways to address the challenges of teaching statistics at universities in Mexico, Pinto Sosa (2020) suggests reviewing and following up on research recommendations on statistical education related to college curricula. He emphasizes the need to integrate research-based knowledge into educational practices. In this context, we present an overview of lecturers' teaching and assessment practices at college statistics courses in Mexico concerning the recommendations of the GAISE College Report (2016). We posed two research questions: 1) how do the lecturers' teaching and assessment practices align with the GAISE recommendations?, and 2) what academic variables are associated with the teaching practices concerning the GAISE recommendations? These questions address the need to evaluate the teaching and assessment practices of statistics lecturers, identifying their strengths and weaknesses about proposals put forward by the statistics education research community. The study intends to generate knowledge that addresses the needs of statistics education at the college level.

Below, we describe the practices that each GRs address. We include empirical findings from four studies –Fry et al. (2014), Hassad (2011), Legacy et al. (2024); and Zieffler et al. (2012)– that explicitly assessed the teaching and assessment practices of college lecturers using the GRs.

2 The GAISE recommendations

We adopted the GRs as a framework to explore the teaching and assessment practices of college lecturers because they encompass well-known proposals for teaching statistics at this level.

2.1 Recommendation 1: teach statistical thinking

Fostering statistical thinking involves teaching statistics as a process of inquiry for solving real-world problems and making decisions (GAISE College Report, 2016). The PPDAC inquiry cycle (Problem, Plan, Data, Analysis, Conclusion) proposed by Wild and Pfannkuch (1999) elucidates the statistical problem-solving process that statisticians commonly employ when solving real-world problems. For students to understand this cycle, it is recommended that it be taught as a complete process, not in piecemeal fashion (Chance, 2002). The proposal for developing statistical thinking further suggests implementing activities that focus on learning how to formulate questions and use multivariate data. Because this type of data presents statistical questions that require exploring relations among study variables, it challenges students to think critically and respond to current issues in their professional fields (GAISE College Report, 2016).

Empirical studies have observed teaching practices that align with this recommendation. Hassad (2011), for instance, found that lecturers "usually" ($N = 227$) promoted critiquing research articles and integrating statistics with other subjects, while Zieffler et al. (2012) observed that

74% ($N = 101$) discussed with their students the need to base decisions on evidence (data) and the study of variability as the core of statistics at least "some of the time". In Fry et al.'s work (2014), over 50% of lecturers ($N = 492$) "repeatedly" addressed the need to base decisions on evidence (data) and placed the study of variability at the core of statistics. Legacy et al. (2024) affirmed that 70% of their subjects ($N = 228$) indicated that they placed "moderate" or "major" emphasis on students' understanding of the importance of variability and the ability to critically assimilate statistically-based results reported in popular media, more than 50% emphasized that they had their students pose research questions, 40-50% stated that they stressed data collection and study design, and, finally, that they prioritized producing and interpreting summaries and visualizations of univariate and bivariate data over multivariate data.

2.2 Recommendations 2: focus on conceptual understanding

Teaching statistical thinking also entails fostering the comprehension of statistical concepts to correctly apply the tools and procedures needed to answer statistical questions about a dataset (GAISE College Report, 2016). It is suggested, moreover, that introductory statistics courses should avoid teaching statistics as a set of formulas, mathematical calculations, or methods, with no reference or application to real-world problems. In this regard, Wilks (2006) proposes that students should be led to "concentrate on fundamental concepts and basic skills in a graduated manner" (p. 41). One way to do this involves using technology to facilitate performing complex numerical analyses as students discover and understand statistical concepts, experiment with data, and focus on interpreting results (Xu et al., 2014).

Hassad (2011) reported that lecturers' practices fail to adequately promote conceptual understanding since they only "sometimes" emphasize rules and formulas as a basis for subsequent learning, or elucidate the mathematical underpinnings of each statistical test, though they demand that students adhere to procedures in the textbook and complete drill and practice exercises (mathematical) for each topic. Zieffler et al. (2012) indicated that 74% of lecturers encouraged students to perform step-by-step calculations to compute answers to problems at least "some of the time".

In an effort to evaluate whether lecturers' teaching focused on conceptual understanding, Legacy et al. (2024) asked their study group to indicate their level of agreement on the importance of assessing (i) student's reasoning about key statistical ideas; and (ii) their procedural skills. Results showed that almost all subjects (96.5%) "agreed" or "strongly agreed" on the first point, while 66.1% expressed agreement on the second.

2.3 Recommendation 3: integrate real data with context and purpose

Promoting statistical thinking involves using real data to solve problems and judge real situations (Wild & Pfannkuch, 1999). Statistics requires an understanding of data, so it is necessary to motivate the use of data from distinct contexts for real purposes. The broader context of the data plays an essential role in learning from a real situation; indeed, knowledge of context is necessary to answer statistical questions, to understand how and why the data were generated or collected, and to make sense of statistical results (Pfannkuch, 2011). Using real data that are interesting for students encourages them to reflect on statistical concepts (GAISE College Report, 2016), while data from problems related to their professions can motivate them to learn statistics and make the process more enjoyable (Jolliffe, 2007).

In many cases, however, various factors make firsthand data collection unfeasible. Lecturers can, of course, work with data collected previously, but it is essential to know the context of the data (e.g., the kinds of variables identified and how they were measured). Large amounts of data available through open sites can be obtained and used in academic activities. In this case, the suggestion is to ask appropriate questions about how real data are generated and analyzed, as this should spark students' interest in thinking about the importance of the data and contribute to the development of statistical thinking (GAISE College Report, 2016).

In practice, lecturers "usually" recognized the importance of real-life data for class demonstrations and assignments (Hassad, 2011). In Zieffler et al.'s study (2012), 74% of the lecturers discussed students' difficulties in obtaining good-quality data at least "some of the time". Fry et al. (2014) reported that a much lower percentage of lecturers (37.2%) "repeatedly" addressed difficulties involved in obtaining good-quality data, whereas Legacy et al. (2024) found that 67.9% of lecturers stated that students see and use real data "most of" or "all" the time in their classes, and 71.8% affirmed that they collected their own data.

2.4 Recommendation 4: Foster active learning

Active learning has been recognized as a key component of introductory statistics courses (Kvam, 2000) because it involves "students in doing things and thinking about what they are doing" (Bonwell & Eison, 1991, p. iii). Active learning can be promoted through instructional activities that lead students to discover, construct, and understand important statistical ideas while also engaging in statistical thinking. For instance, activities grounded in real data with a motivating question promote think-pair-share discussion and physical explorations and encourage learners to make predictions before analyzing data (GAISE College Report, 2016). Research projects (Evans, 2005; Kvam, 2000), computer-based classes (Harkness, 2005), and peer assessment and feedback (Rossman, 2005) are other activities that foment active learning.

Without doubt, active learning demands more class time to orient students so they can participate effectively in discussions. It also requires "timely and helpful feedback" (Rossman, 2005, p. 9). While the active learning approach certainly presents challenges, Kvam (2000) points out that students enjoy learning about the application of statistical methods more than traditional classroom teaching. On this topic, Zieffler et al. (2012) indicated that at least "some of the time" 74% of lecturers used small group class discussions to help students learn statistics. Legacy et al. (2024) indicated that 48.4% of the lecturers they studied "agreed" and "strongly agreed" that they presented course content primarily through student-oriented activities, that 57.3% encouraged students to discover ideas on their own, and that 70.9% required students to work cooperatively to complete classroom work/activities.

2.5 Recommendation 5: use technology to explore concepts and analyze data

It has been suggested that technology is an effective teaching aid for handling, exploring, and visualizing data and for exploring conceptual ideas (GAISE College Report, 2016). The rapid development of information technology offers various tools that can be applied in statistics teaching to support student learning. According to Xu et al. (2014), using computers and statistical software fosters the development of desirable skills, such as statistical thinking. They further point out that technology strengthens statistics curricula by creating synergy with content and pedagogy, moreover, it can help assess student learning.

The numerous technological tools available for statistics teaching (e.g., web pages or resources, data repositories, online textbooks, scientific journals, applets, simulators, graphs, calculators, virtual environments, spreadsheets, educational software, statistical software packages) constitute an enormous universe of teaching aids, but one of the most important considerations regarding technology is its accelerated pace of development. Lecturers should welcome online tools and physical devices, "use the best technology available" (GAISE College Report, 2016, p. 20), and evaluate the feasibility of acquiring and implementing technological resources that align with the policies established by their institutions.

According to Fry et al. (2014), Hassad (2011), and Zieffler et al. (2012), lecturers "usually" or at least "some of the time" used computer programs to help students explore and analyze data and understand statistical concepts. However, Fry et al.'s analysis revealed that subjects reported spending more time analyzing data with students than understanding statistical concepts. In contrast, results in Legacy et al. (2024) showed that 94% of lecturers used technology to help students understand concepts. Fry et al. (2014) also reported that 91.7% of lecturers affirmed that their students used technological tools other than hand calculators in their courses. The breakdown for students' work activities and assignments (e.g., homework, projects) was as follows: 77.8% used statistical analysis packages (e.g., Minitab, SPSS, JMP, StatCrunch), 40.6% utilized graphing calculators with built-in statistical functions, 39.7% worked with spreadsheets (e.g., Excel), and 6.5% employed conceptual software (e.g., TinkerPlots, Fathom). Turning to the lecturers, 55.6% stated that they used web applets to deliver course content. Legacy et al. (2024) reported that the main technological tool that lecturers used to help students analyze data was desktop or web-based software (89.5%), while the rest used calculators with (22.1%) and without (36.2%) built-in statistical functions. Lecturers used Excel (48.4%) more than other software to analyze data. Fathom was among the least-used resources (1.1%).

2.6 Recommendation 6: use assessments to improve and evaluate student learning

The GAISE College Report (2016) recognizes both formative and summative assessment and encourages lecturers to "maximize opportunities to include formative assessments into their courses rather than focus exclusively on summative assessments" (p. 22). However, it is also widely acknowledged that "assessing statistical thinking is much more difficult than assessing the ability to perform routine calculations" (Bidgood et al., 2010, p. xv) since it requires reasoning processes to interpret and draw conclusions from statistical analyses (GAISE College Report, 2016). The principal goals of assessment, then, are to measure (i) students' knowledge and understanding of statistical ideas, and (ii) their ability to apply statistical methods to real problems (Jolliffe, 2007, 2010). Using various assessment methods, both traditional and alternative, in the classroom is also highly recommended. These can include quizzes, statistical projects, lab reports, final projects, written reports (e.g., essays, reflective journals, write-ups on in-class or computer lab activities), case studies, portfolios, open-ended problems, concept maps, and critiques of statistical idea or issues in the media (GAISE College Report, 2016; Garfield & Chance, 2000; Garfield et al., 2010).

Research on the successful experiences of lecturers in six countries (UK, New Zealand, Argentina, USA, Ireland, and Australia) has demonstrated the wealth of assessment methods they have used in their teaching of statistics courses in distinct fields at the tertiary level, including psychology, biology, business, health, and agriculture (Bidgood et al., 2010). In their teaching they have found that elaborating reports and evaluating media articles are especially efficacious ways to assess students' statistical thinking (e.g., Budgett & Pfannkuch, 2010; Forster & Wild, 2010).

Hassad (2011) noted that lecturers "sometimes" included written reports on data analysis as an assessment method. In their study, Zieffler et al. (2012) listed 10 assessment practices for lecturers. They reported that 86% of subjects agreed with six of those methods and that 50% agreed with eight or more. The options included applying various assessment types (e.g., homework, quizzes, projects, minute papers, problems that involve real data, etc.), using assessments designed to show if students use statistical language properly, evaluating their abilities to use formulas and technology to produce numerical summaries of a data set, requiring them to interpret the results of data analyses, asking them to critically examine statistics in the media, and successfully completing a statistical investigation.

In this regard, Fry et al. (2014) calculated the percentage of students' grades that lecturers based on assessments of their abilities. They found that 38.5% ($SD = 21.9$) centered on the ability to interpret the results of statistical analyses and 37.1% ($SD = 24$) on correct reasoning about important statistical concepts. Much lower percentages were related to critically examining statistics in the media (12.4%, $SD = 15.6$) and successfully completing a statistical investigation (17.5%, $SD = 18.8$). Legacy et al. (2024) reported that lecturers "agreed" or "strongly agreed" with the importance of collaborative (39.7%) and formative assessment (63.4%) and indicated that their methods included assessing students' ability to critically evaluate statistics-based results reported in the popular media (67.9%), procedural skills (66.1%), and reasoning about key statistical ideas (96.5%).

3 Method

The present paper derives from a national study that explored and described the characteristics of the teaching and assessment of statistics by Mexican college-level lecturers considering the 2016 GAISE College Report recommendations (Rivera Pérez, 2023). This paper has a correlational scope since, in addition to describing teaching and assessment practices concerning the GRs, it aims to examine the academic variables associated with those practices.

3.1 Study design

We carried out a pilot study to design and implement the first version of the survey. The content items on teaching and assessment practices resulted from a comprehensive theoretical review of the GRs, the statistical thinking model (Wild & Pfannkuch, 1999), and instruments like those applied by Garfield et al. (2002) and Bargagliotti et al. (2020), and the one proposed by Gómez-Blancarte et al. (2021). This version of the survey included 76 items related to the GRs, as well as questions about demographic and academic variables. These items included ordinal scale responses, single- or multiple-choice questions, and open-ended questions.

The ordinal scale items included six response options on a 5-point scale: the responses "the course does not require it" and "never" both = 0, "just above what is sufficient" = 1, "exclusively what is sufficient" = 2, "a little more than what is sufficient" = 3, and "much more than what is sufficient" = 4. By "sufficient", we refer to content that is required according to the curricular requirements or lecturers' own perceptions. The option "the course does not require it" was equivalent to "never". We chose to include it to allow lecturers to justify why they did not include a certain content. The pilot survey was applied to 34 volunteer lecturers who taught statistics at the college level from May to July 2020. Responses allowed us to review and validate the content and reliability of the items using descriptive statistical analyses, correlation of the items, and reliability analysis. Based on the results, some items with no or minimal contribution were eliminated, new items were designed, and the wording was improved.

The final survey also included 76 items. Like the Statistics Teaching Inventory v. 3 (STI-3) instrument reported in Legacy et al. (2024), our survey provides insights into teaching and assessment practices regarding the six recommendations of the 2016 GAISE College Report. In addition to covering these recommendations, our survey includes items on instructor demographics and academic data, providing a broader understanding of lectures' practices. By contrast, the STI-3 includes other items related to computational practices and data science.

Both instruments contain items related to more than one GR. Legacy et al. (2024) report that two items in GR 2 are also part of the five items included in GR 6, while six items included in GR 5 are also part of the items included in GR 1. The Results section addresses the items that appear in more than one GR. We want to note that given an item's occurrence in more than one GR, our instrument cannot differentiate between the six GRs. We discuss this further in the Conclusions section.

3.2 Data collection

The survey was conducted strategically and electronically because of the COVID-19 pandemic and to access as many respondents as possible (Cohen et al., 2018). Data collection ran from December 2020 to July 2021. College-level lecturers were invited if they taught statistics courses or had done so for at least two years before the study period. The invitation was sent through the academic authorities of the participating institutions. A database of 420 colleges was compiled from the National Association of Universities and Institutions of Higher Education. For each one, we identified the relevant academic authorities and sent an e-mail to

Table 1 Confirmatory factor analysis fit indices

Factorial model	χ^2	df	$\frac{\chi^2}{gl}$	SRMR	RMSEA	TLI	CFI
4-factor model	886.802	293	3.02	0.05	0.075	0.892	0.903

Note: SRMR = standardized root mean square residual, RMSEA = root mean square error of approximation, TLI = Tucker-Lewis index, CFI = comparative fit index

fully inform them of the research goals, ensure them that all data collected would be handled confidentially, and stress the importance of their lecturers' support. The message included the electronic link to the digital file that contained the survey, so the authorities were aware of the instrument's content. We also sent an e-mail to the Mexican Association of Statistics to disseminate the invitation among lecturers who teach statistics in colleges. A total of 750 lecturers responded: 33.2% were female, and 66.8% were male; the majority (53.7%) have a master's degree; 90.7% work in public, and 9.3% in private schools. This purposive sample reflected a broad range distributed in all 32 states, which is suitable given that our aim was to examine relations between lecturers' academic variables and their teaching and assessment practices rather than to calculate population estimates (Viswanathan, 2005).

3.3 Survey validation

With the total set of data, a descriptive statistical analysis was used to examine the characteristics of the 33 items. The database was then randomly divided into two data sets ($n_1 = 364$ and $n_2 = 358$); the responses of 28 lecturers who did not use technology were eliminated from the analysis. The first data set was used to perform an exploratory factor analysis (EFA) to establish components with the fewest possible items and provide evidence of construct validity. The second was utilized to perform a confirmatory factor analysis (CFA) to check the fit of the proposed model in the EFA (Lloret-Segura et al., 2014; Taherdoost et al., 2014).

The EFA applied Cronbach's alpha reliability analysis, the Kaiser-Meyer-Olkin sample adequacy test, parallel analysis, and the average minimum partial correlation procedure to select the number of factors to be extracted (Taherdoost et al., 2014). Results provided a 4-dimensional model with a percentage of the accumulated variance of 93.81%. The maximum likelihood mean-adjusted component extraction method with oblimin rotation and Kaiser normalization was also employed, which efficiently reduced the ordinal scale items from 33 to 26 (items with factor loadings greater than 0.4, see Supplementary material file). The CFA was used to corroborate that the model fit the data within the structural equation SEM module of Stata v.17 (Table 1).

Since the CFA's fit indices were all sufficient (Lloret-Segura et al., 2014), the 4-factor model obtained can be considered acceptable. Finally, to determine the reliability of the items, we calculated Cronbach's alpha reliability coefficient (α), the mean extracted variance (VME), and the composite reliability coefficient (ω) of the four dimensions and the overall score: *Dimension 1* (11 items, $\alpha = .900$, VME $= .459$, $\omega = .902$); *Dimension 2* (3 items, $\alpha = .740$, VME $= .709$, $\omega = .742$); *Dimension 3* (6 items, $\alpha = .935$, VME $= .590$, $\omega = .936$); and *Dimension 4* (6 items, $\alpha = .893$, VME $= .491$, $\omega = .896$). Therefore, overall scores were based on 26 items ($\alpha = .949$, VME $= .950$, $\omega = .958$).

3.4 Data analysis

To answer our first research question, we analyzed the 26 items included within the four dimensions, as well as items 14B, 14C, 14F, 14I, 15, 17, 20, and 21, which provide additional information regarding GRs. To answer the second research question, we analyzed ordinal variables (items 27 and 28, see Table 2) and numerical variables (items 24, 25, and 33-35, see Table 3). For the statistical analysis of the dimensions, a score per dimension was calculated by totaling the scores obtained on each of the items included in that dimension. The remaining items were analyzed using frequencies, percentages, and descriptive statistics. All analyses were performed using the data set of 358.

The Shapiro-Wilks test was performed at a significance level of $p < .05$ to determine whether the score for the dimensions fit a normal distribution. According to the test results for each dimension, this did not occur, so we used Spearman's correlation test to examine the relation of the ordinal and numerical variables to the dimensions.

4 Results

4.1 Lecturers' teaching and assessment practices concerning the GAISE recommendations

We present the results of the 26 items in the four dimensions representing the teaching and assessment practices lecturers encourage in their statistics courses concerning the GRs. Results were obtained by calculating the percentage of lecturers whose responses on these items indicated scores 3 and 4. To give more information about those practices, we also present the results of the items 14B, 14C, 14F, 14I, 15, 17, 20, and 21.

Dimension 1

Table 4 shows the percentage of the 11 items grouped in dimension 1, which encompasses practices related to four of the six recommendations (1, 3, 4, 6).

All items included in Dimension 1, except for item 16C, inform us about GR 1. This is because they relate to the phases of the PPDAC statistical inquiry cycle and the interrogative cycle (item 13F) of statistical thinking. 37.7% of

Table 2 Descriptive data on the ordinal variables

	f	%
Experience in data analysis		
No experience	9	2.5
Very little experience	102	28.5
Some experience	189	52.8
A great deal of experience	58	16.2
Statistics as an area of expertise		
Your primary area of expertise	91	25.4
One of your secondary areas of expertise	137	38.3
Not one of your areas of expertise, but you know enough to teach it at the college level	108	30.2
A subject you teach, though you acknowledge that you do not know enough about statistics to teach it at the college level	10	2.8

Table 3 Descriptive data on the numerical variables

	n	*Min*	*Max*	*M*	*Mdn*	*SD*
Years teaching statistics at college level	354	0.0	35.0	6.0	8.2	7.2
Training courses in teaching statistics	345	0.0	10.0	1.0	2.0	2.3
Average number of students per statistics group	349	0.0	60.0	26.0	26.4	10.6
Hours per week that you teach statistics	355	0.0	30.0	6.0	8.6	5.8
Number of groups	355	0.0	6.0	2.0	2.0	1.2

Table 4 Percentage of responses with scores 3 and 4 for the items in dimension 1

Item	Score 3	Score 4
8F. Encourage students to formulate statistical research questions as they explore a real-problem.	37.7	30.4
8G. Encourage students to explore the context of the problem to discuss ideas (variables, population, sample, sample size, type of sampling, among others) needed to solve it.	38.8	34.4
8H. Encourage students to use instruments (e.g., questionnaires, interviews) to collect real data.	29.9	26.3
8I. Promote activities that allow students to choose and justify the statistical models or tools needed for data analysis.	38.5	26.0
8J. Encourage students to make decisions based on statistical results when dealing with a real-world problem.	36.3	38.3
13B. Use data from repositories or databases to help address a problem (e.g., health, marketing, economics databases, etc.).	33.8	20.4
13F. Encourage students to generate, seek, criticize, judge, and interpret information to solve a problem.	39.9	29.3
16C. Assess students' collaborative work.	39.1	21.2
16D. Assess the production of written reports derived from statistical research work.	31.8	22.9
16E. Assess students' interpretations of statistical results published in different media (e.g., newspapers, magazines, news reports, books, scientific articles, among others).	25.7	18.7
16K. Assess students' ability to conduct statistical research, including posing a problem, proposing a statistical research question, collecting real data, performing statistical analysis, and drawing conclusions based on the analyses and the context of the problem.	27.9	22.3

lecturers, on a score of 3, encourage students to formulate research questions (Problem); 38.8% encourage students to explore the context of the problem to discuss statistical ideas such as variables, population, sample, sample size, type of sampling (Plan); 29.9% promote the use of instruments for collecting real data, or 33.8% using databases (Data); 38.5% allow students to choose and justify statistical models or tools for data analysis (Analysis); and, on the highest score, 38.3% encourage students to make decisions based on statistical results when dealing with a real-world problem (Conclusions). However, in both scores, a minor percentage of

Table 5 Percentage of responses with scores 3 and 4 for the items in dimension 2

Item	Score 3	Score 4
8C. Propose activities that allow students to use statistical models (graphs, distributions, regression models, etc.) to look for patterns, relations, trends, or features of interest in the data.	38.5	39.4
8D. Encourage students to interpret the results of a statistical analysis in the broader context of the data.	34.6	53.6
8E. Promote statistics teaching as a discipline that seeks to provide information to solve problems or make decisions.	31.0	60.3

lecturers assess students' ability to conduct a full statistical research cycle (item 16K).

In addition, data collection instruments and databases from different sources (items 8H and 13B) are two critical aspects of integrating real data with a context and purpose (GR 3). Four assessment practices (GR 6) were also represented in this dimension (items 16C-16K). On a score of 3, the lecturers assessed students' collaborative work (39.1%), written reports (31.8%), interpretation of statistical results published in different media (25.7%), and abilities to develop the entire inquiry cycle (27.9%). These assessment practices and the others in this dimension relate to active learning (GR 4), so they support that these lecturers foster this kind of learning.

Assessing the production of written reports and students' interpretations of statistical results published in different media are recognized ways to assess students' statistical thinking (GR 1). Another important recommendation is to provide students with experience in multivariable thinking (GR 1). In this regard, lecturers most frequently performed data analysis in their statistics courses (item 15) was descriptive (88.5%), and the least frequently performed analysis was multivariate analysis (15.9%). However, some lecturers reported performing linear regression (72.3%) and correlation (69.3%).

Dimension 2

This dimension retained the minimal factor grouping items related to GRs 1, 3, and 4 (Table 5). The three items relate to practices regarding GR 1. A high percentage (60.3%) of the lecturers encourage teaching statistics as a discipline that helps solve problems or make decisions and stressed the importance of encouraging students to interpret the results of statistical analyses in the broader context of the data (53.6%), which is a key aspect of the practical application of integrating real data with a context and purpose (GR 3) and fostering active learning (GR 4).

On a score of 4, 39.4% of lecturers propose activities that lead students to explore statistical models and identify features of interest in the data, two steps that are necessary for data analysis (GR 1). These activities give students practice in selecting appropriate techniques, interacting with data, and actively working (GRs 3 and 4).

Dimension 3

All six items in dimension 3 (Table 6) correspond to lecturers' use of technology (GR 5), and item 22C allows us to assess whether lecturers foster conceptual understanding (GR 2).

A high percentage (35.5%) of these lecturers, on a score of 3, use technology with their students to perform numerical procedures, while a lower percentage (29.6%) use it to explore statistical concepts (GR 2). On a score of 4, the lecturers reported using technology primarily to transform data into different representations (31.6%), perform numerical procedures (31.3%), and perform exploratory data analyses (30.7%).

Responses in item 20 show that Excel (94.1%) and the calculator (67.3%) were the technological tools most often mentioned. They also reported using specialized programs for statistical analysis, such as Minitab (33.2%), SPSS (20.4%), or R (13.4%). The least-used software programs (0.6%) were JMP, Epi-info, and Fathom. Lecturers spent approximately half the semester with students performing statistical analyses (item 14B) and understanding the program's content (item 14C) using technological tools. The principal dynamic that best fits the use of technology in lecturers' statistics courses (item 21) was teaching from a computer in the classroom while students practiced on their own computers in class or at home (61.2%).

Dimension 4

All items in dimension 4 correspond to GR 6 (Table 7); the 16I item also relates to GR 2. On a score of 3, a significant percentage score of 3 of the lecturers' assessment practices focused on procedural skills such as assessing students' ability to appropriately apply statistical methods (43.9%), using formulas to derive numerical results from a data set (40.5%), and relating concepts (40.2%).

On a score of 4, lecturers' assessment practices focused on assessing students' interpretation of statistical data displayed in representations (39.7%) and statistical analyses (38.8%). Lecturers indicated that they spent 55.14% ($SD =$ 36.58) of the semester applying assessment instruments (item 14I). The assessment activities most often used by lecturers (item 17) were class exercises (89.1%), homework (86.9%), and exams (70.9%), though a significant percentage (64.8%) considered statistical projects and collaborative activities (60.3%) as assessment resources. Lecturers indicated that 47.43% ($SD = 32.08$) of the semester time is

Table 6 Percentage of responses with scores 3 and 4 for the items in dimension 3

Item	Score 3	Score 4
22A. Perform exploratory data analysis (e.g., missing data, outliers, calculating frequencies or percentages, among other basic descriptive procedure).	32.1	30.7
22B. Perform inferential data analysis (e.g., correlations, hypothesis testing, contingency tables, etc.).	31.8	29.1
22C. Explore features of statistical concepts (e.g., how removing outliers affects mode and median).	29.6	24.9
22D. Explore a data distribution graphically (e.g., identify measures of central tendency, explore variability in data, identify biases, etc.).	34.1	29.9
22E. Perform numerical procedures on statistical concepts (e.g., calculating measures of central tendency or dispersion, correlation coefficients, among others).	35.5	31.3
22F. Transform a data set into multiple representations (e.g., tables, statistical graphs) and derive various kinds of information from the data.	32.4	31.6

Table 7 Percentage of responses with scores 3 and 4 for the items in dimension 4

Item	Score 3	Score 4
16A. Assess that students apply statistical methods appropriately.	43.9	31.3
16B. Assess that students correctly interpret the information displayed in various statistical representations (e.g., tables, graphs, statistical summaries).	38.8	39.7
16F. Assess students' ability to use formulas to derive numerical results from data set.	40.5	29.1
16G. Assess students' ability to construct representations of data (e.g., tables and graphs).	37.7	33.2
16H. Assess how students interpret the results of statistical analyses.	36.9	38.8
16I. Assess students' ability to relate one concept to another (e.g., mean and dispersion).	40.2	34.1

dedicated to students carrying out statistical projects (item 14F). The activities seldom used as assessment tools were essay writing (20.7%), self-assessment (17.3%), and laboratory reports (12.3%).

4.2 Variables associated with the dimensions of teaching and the assessment of statistics according to the GAISE recommendations

To examine the relationship between the study variables and each dimension, a Spearman's correlation test with Bonferroni adjustment for 28 comparisons ($p < 1.78 \times 10^{-3}$) was performed. The results showed a weak positive association for all variables. The variable *experience in data analysis* showed the highest correlations: Dimension 1 ($r_s = 0.345$), Dimension 2 ($r_s = 0.332$), Dimension 3 ($r_s = 0.363$), and Dimension 5 ($r_s = 0.305$).

5 Discussion

We explored the teaching and assessment practices that Mexican lecturers encourage in their college statistics courses in relation to the recommendations of the 2016 GAISE College Report. Since these recommendations are designed to guide what (GRs 1-2) and how (GRs 3-6) to teach statistics, we discuss our results regarding these two targets.

5.1 What do lecturers teach?

Our lecturers reported that they place more emphasis on teaching key aspects of statistical thinking (GR 1) by promoting statistics teaching as a discipline that seeks to provide information to make decisions (60.3%), fostering practices involved in the PPDAC inquiry (i.e., formulating statistical research questions, 37.7%; exploring the context of the problem to discuss statistical ideas, 38.8%; collecting real data, 29.9%; using repositories or databases, 33.8%; deciding on and justifying statistical models or tools to analyze the data, 38.5%; interpreting statistical results regarding data context, 53.6%; and encouraging students to make decisions based on statistical results when dealing with a real-world problems (38.3%). In addition, they provide opportunities for students to experience multivariable thinking (linear regression, 72.3%, and correlation, 29.3%).

It is well established that those teaching practices promote statistical thinking. Zieffler et al. (2012) and Fry et al. (2014), for instance, reported that 74% and over 50% of the lecturers they studied addressed the need to base decisions on evidence. Legacy et al. (2024) also found that lecturers emphasize the importance of having students pose questions (>50%), collect data, and design studies (40-50%). Although critiquing research articles is an assessment activity to foster statistical thinking, as lecturers studied by Hassad (2011) and Legacy et al. (2024), our lecturers emphasize it less (18.7%). Nevertheless, they place more emphasis on assessing the production of written reports from statistical research (31.8%).

Respondents fostered conceptual understanding (GR 2) using technology to help students explore features of statistical concepts (29.6%) and focused on assessing their ability to relate concepts (40.2%). However, technology is used primarily to help students apply statistical methods appropriately (43.9%). Here, conceptual understanding received less emphasis when using technology than during assessment. Like Hassad (2011) and Zieffler et al. (2012) reported, our lecturers mentioned some unfavorable practices for promoting conceptual understanding. In contrast, the results of Legacy et al. (2024) show that almost all lecturers assessed students' reasoning about key statistical ideas, which fosters an understanding that is more conceptual than procedural.

5.2 How do lecturers teach?

Results show that respondents follow recommendations that help develop statistical thinking, though with some inconsistencies. Regarding using real data (GR 3), while a 53.6% promote, much more, practices that encourage students to interpret statistical results in the broader context of the data, a lower percentage indicated using real data, whether collected by students (26%) or obtained from repositories or databases (20.4%). Legacy et al. (2024) found that 67.9% of lecturers said that students see and use real data "most" or "all" the time, and 71.8% indicated that students collect data.

Since activities grounded in real data, research projects, computer-based classes, and collaborative assessment (Evans, 2005; GAISE College Report, 2016; Harkness, 2005; Kvam, 2000; Rossman, 2005) provide active learning (GR 4), respondents appear to put this teaching approach into practice. To a greater or lesser extent, they promote activities from the PPDAC cycle, enable students to generate, seek, criticize, judge, and interpret information to solve problems, allow them to choose and justify the statistical models or tools needed for data analysis, use technology, and assess students' collaborative work and written reports. However, active learning entails both doing and thinking –that is, understanding statistical ideas– but lecturers' practices tend to emphasize procedural skills over exploring conceptual understanding when using technology. Legacy et al. (2024), for instance, reported that only 57.3% of their lecturers encouraged students to discover ideas.

Although our lecturers incorporated technology (GR 5) into their courses, two main concerns remain: the type of technological tools they use and how they use them. Excel was the main technological tool used (90.1%). The predominant use of Excel coincides with the report by Pinto Sosa et al. (2007). Despite technological advances and the many statistical software programs available, Excel is still the technological tool most often used by Mexican lecturers in their teaching. For the U.S., Fry et al. (2014) reported that 77.8% of lecturers used statistical analysis packages, and 39.7% used spreadsheet tools like Excel. However, in the most recent study by Legacy et al. (2024), Excel was the tool most often used (48.4%). Suggested software for statistics education (Fathom, TinkerPlots) was used less by our respondents but also by the lecturers surveyed in the U.S. by Fry et al. (2014) and Legacy et al. (2024).

Respondents used technology mainly for elaborating representations (31.6%), performing numerical procedures (31.3%), and exploratory data analysis (30.7%). In contrast, 24.9% used it to explore features of statistical concepts. Fry et al. (2014) also indicated that lecturers devoted more of students' time to analyzing data than to understanding statistical concepts. Legacy et al. (2024) showed a distinct trend as 94% of lecturers used technology to help students understand concepts.

The lecturers' assessment practices (GR 6) tend to focus much more on interpreting the results of statistical analyses (38.8%) and information displayed in various representations (39.7%), and with little more emphasis on the proper application of statistical methods (43.9%), and the use of formulas to derive numerical results (40.5%). They also indicated that they assess, much more, students' ability to relate concepts (34.1%), produce written reports (22.9%), conduct statistical research (22.3%), and interpret statistical results published in media (18.7%). These results show variation in the use of resources recommended to assess students' procedural skills and conceptual understanding. Legacy et al. (2024) indicated that lecturers' methods included assessing students' procedural skills and reasoning about key statistical ideas, with the latter receiving greater emphasis.

The most common assessment methods (class exercises, homework, exams) are traditional and focused on procedural skills. Class exercises and exams are still the most popular approaches, as Pinto Sosa et al. (2007) have reported. Assessment activities like writing reports, doing statistical projects, and critically interpreting statistical results in the media are more important for assessing students' statistical thinking. In this case, 64.8% of lecturers used statistical projects for assessment, but only 22.3% indicated that they, much more, evaluated students' ability to conduct the whole process of statistical research. Fry et al. (2014) also found that completing a statistical investigation was seldom used.

Some practices involving technology and assessment revealed that a significant percentage of these lecturers should pay more attention to developing the PPDAC cycle in its entirety since they indicated that they utilize only certain key aspects of each phase, though they do assess, to some extent, the whole statistical research process. When using technology, they tend to focus more on developing procedures than fostering a conceptual understanding of statistical ideas or concepts. Our empirical results are, therefore, similar to those of Cruz López and Ojeda Ramírez (2021) and Pinto Sosa (2020), who identified that the promotion of statistical thinking in the syllabi of university statistics courses in Mexico is weak because they tend to emphasize data processing.

Our four dimensions retain items related to the six GRs. The first dimension includes items mainly related to statistical thinking practices in teaching and assessment that do not necessarily involve the use of technology to promote conceptual understanding. Dimension 2 grouped a small number of items that highlight two main goals of statistical thinking: using statistics to solve problems and make decisions by exploring data and linking statistical and contextual knowledge. Dimensions 3 and 4 were the only ones that group items corresponding to GR 5 and GR 6, respectively. Dimension 3 represents practices regarding the use of technology, and Dimension 4 represents assessment practices.

6 Conclusions and final remarks

Our results show that the teaching and assessment practices of the lecturers surveyed align with most of the GRs to at least some extent, but it is important to note, on the one hand, that there is still a group of lecturers who place less emphasis on them, and, on the other, the lecturers who do follow them with little to much more emphasis apparently include unfavorable suggestions. Results suggest that lecturers must improve their use of technology and their assessment methods. They must employ other computer programs in addition to Excel to shift the focus from statistical analysis and constructing visual representations toward conceptual understanding. They also need to employ varied assessment activities to foster awareness of issues related to statistical thinking.

The variable *experience in data analysis* showed the highest correlation, although they were weak, to the lecturers' teaching and assessment practices regarding the GRs, particularly with GR 5 (Dimension 3). This variable pertains to the statistical and technological knowledge that could assist lecturers in conveying current trends in statistics education to the classroom. However, our results do not allow us to make predictions, establish causal relationships, or generalize. Further content revision of our survey is needed, primarily to prevent items from appearing in more than one GR. This revision will help us better discriminate among these six recommendations. Our four-dimensional model reveals that technology use (GR 5) and assessment (GR 6) practices were more distinguishable than GRs 1-4.

In addition to the survey, contrasting observations and interviews could help corroborate our results. Future research should include multiple sources of information production, such as classroom observations and interviews, as this would provide more detailed knowledge of how lecturers understand and implement the GRs in their teaching and assessment practices.

This study contributes to the knowledge needed to assess current teaching practices in statistics and evolve university curricula from a global and local perspective, as Pfannkuch suggests (2018). Our view of teaching and assessment practices in college education in Mexico may not be exclusive to this country, for as Pinto Sosa (2020) observed, Latin America produces similar results. Our survey can guide other researchers in exploring the situation in their local contexts. Our four-dimensional model lays the groundwork for future studies seeking to explore correlations between teaching and assessment practices regarding GRs and lecturers' backgrounds. There is a vast potential for research in this area, and our study may serve as a reference point. For instance, it could be used to relate the effect size found in our study to those found in future studies, as Cohen et al. (2018) suggest this is necessary for better interpreting coefficient correlations.

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Declarations

Competing Interests The authors declare no competing interests.

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