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Effects of Individual and Situational Characteristics on the Use of Student-Centered Pedagogy in Calculus I

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Investigations into attrition of STEM-intending students indicate that poor experiences in introductory courses are at least partly to blame, specifically the students' frustration with lecture-driven teaching methods. In this research, hierarchical linear modeling is used to identify the individual and situational characteristics of instructors who support the use of student-centered pedagogy in Calculus I. Of specific interest are the effects of class size and perceived departmental support on an instructor's employment of student-centered pedagogical approaches. Overall, the effects of class size and support are functioning as the literature would suggest: instructors with large classes and minimal departmental support report lower usage of student-centered pedagogical approaches. The interesting finding is that these effects are more salient at the institutional level as compared with the instructor level. By analyzing national data gathered from 490 instructors distributed across 160 institutions, the findings of this research provide large-scale empirical support for several interview studies that have identified the importance of situational characteristics and highlight the importance of institutional context over the context experienced by individuals. Furthermore, this research suggests that change strategies might be more effectively supported through the department chair and/or course coordinators, as opposed to targeting individual instructors through professional development opportunities.

It is widely reported that the United States (US), as well as many European nations, are struggling to produce sufficient Science, Technology, Engineering, and Mathematics (STEM) graduates at the university level (e.g., Olson & Riordan, 2012; van Langen & Dekkers, 2005). For instance, in the US it is estimated that the number of STEM graduates must increase by an additional one million over current projections to meet the need of workforce demands (Olson & Riordan, 2012). This problem does not appear to be one of disinterest, but rather of retention as it has been reported that as many as 40% of STEM-intending students do not graduate with a STEM degree (Hurtado, Eagan, & Chang, 2010). While student retention, especially in the first year of college, is a complicated issue (e.g., Daempfle, 2003; Gerdes, & Mallinckrodt, 1994: Tinto, 1999), researchers have identified lecture-based instructional practices in introductory courses as a significant contributor to the loss of STEM-intending students.

Many of those students leaving STEM majors cite ineffective teaching methods and uninspiring atmospheres in introductory-level STEM courses, with introductory mathematics courses such as Calculus I often singled out as the primary reason for attrition (Olson & Riordan, 2012; Rasmussen & Ellis, 2013, Seymour, 2006; Thompson et al., 2007). Students are frustrated with what they perceive to be courses overburdened with content and with pacing structures that inhibit comprehension and reflection – a situation they believe is exacerbated by "modes of teaching that suggest that [the faculty] took little responsibility for student learning" (Seymour, 2006, p.4). The research supports these student reports. A recent meta-analysis by Freeman et al. (2014) found that in undergraduate STEM courses, "active learning leads to increases in examination performance that would raise average grades by a half a letter" (p. 8410), and that students in lecture classes are 1.5 times more likely to fail than those in classes where active learning methods are used. However, despite the student retention problems and the amassing research advocating against its usage, lecture is still the predominant instructional practice reported across STEM in general, and in mathematics in particular. As presented in the HERI report, "the data continue to show that nearly two-thirds of faculty across STEM sub-fields utilize extensive lecturing in all or most of their courses" (Eagan, 2016).

In light of the HERI findings and related research, the purpose of this study is a focused investigation of a particular course, Calculus I, and the use of student-centered pedagogy therein. A hierarchical linear modeling approach is used on a national sample to investigate individual and situational characteristics of instructors that influence pedagogical decision-making and to identify factors that support the use of student-centered instructional practices.

Review of Relevant Literature

Given the propensity of extensive lecturing in undergraduate mathematics courses, one might mistakenly assume that instructors' teaching practice is the result of habit or apathy (for a review of such claims, see Weber, 2004). In actuality, case studies of mathematics instructors have found that their instruction is informed by rich belief systems, well-articulated pedagogical goals, and a good deal of thought (e.g. Johnson, 2013; Fukawa-Connelly & Newton, 2014; Jaworski, Treffert-Thomas, & Bartsch, 2009; Lew, Fukawa-Connelly, Mejia-Ramos, & Weber, 2016; Weber, 2012). Additionally, instructors do not teach in a vacuum, with many contextual features influencing what happens in their classrooms.

The literature has cited many reasons why instructors choose to lecture, and not least of these is the belief that lecture is the best method and/or necessary for content coverage (as discussed by Roth McDuffie & Graeber, 2003; Wagner, Speer, & Rosa, 2007; Yoshinobu & Jones, 2012). While we do not wish to discount the enormous influence personal beliefs have on instructional decision-making, we must acknowledge that a bevy of other external circumstances can factor considerably when instructors plan their courses.

These external factors are likely of particular importance because beliefs, values, and knowledge (i.e., conceptions) about teaching are often poor indicators of actual teaching behavior (see Henderson and Dancy, 2007 who cite both research in sociology and education). Accounting for inconsistencies between instructors' conceptions about teaching and their actual practices necessitates taking into account situational characteristics. Defined as "all aspects outside of the individual instructor that impact or are impacted by the instructors' instructional practices" (Henderson & Dancy, 2007, p. 10), these situational characteristics include both easily measurable contextual features such as class size, and those features more difficult to gauge such as departmental support and climate.

Class sizes in introductory STEM courses, such as Calculus I, are often highly variable. For instance, Selinski and Milbourne (2015) found the average class size for Calculus I at PhD-granting institutions to be 52.95 students, with a standard deviation of 53.661. With fluctuation this wide, class size is likely a factor in instructors' pedagogical decision-making. Research by Benton and Pallett (2013) has shown that teaching methods differ according to class size with instructors of large classes being less likely to "involve students in hands-on projects and real-life activities…form teams or discussion groups to facilitate learning, and ask students to help each other understand concepts or ideas." This was echoed by participants in Henderson and Dancy's (2007) study who reported teaching large numbers of students, in lecture hall with seats bolted to the floor, made it "harder to use many research-based methods that focus on interactivity, cooperative learning, and formative assessment" (p. 9).

Related to class size, and perhaps also a contributing factor to teaching practices, is the number of sections offered for a given course. Most US colleges and universities offer multiple sections of Calculus I each semester, with these sections often being taught by a wide range of instructors (e.g., postdocs, adjunct lecturers, graduate students, tenure-track or tenured faculty). As described by Rasmussen and Ellis (2015), multiple sections can create situations where different students are being taught different content or taught in different ways (which can affect what they actually learn). Thus, with the presence of multiple sections, departments usually turn to coordinating certain aspects of the course. This coordination can include course schedules, textbook, homework, exams, exam grading, and quizzes; however, it can be much more extensive. As described by Rasmussen and Ellis (2015), coordination can also include holding regular meetings between instructors, sharing course resources, and providing feedback. In this way, coordination can help to set expectations and norms around teaching, thus influencing the departmental culture.

Departmental norms, expectations, and teaching culture appear to impact an individual's teaching practice in a number of ways. Departmental expectations about content coverage are ubiquitous when discussing decisions about instructional approaches (e.g., Johnson, 2013; Roth McDuffie & Graeber, 2003; Wagner, Speer, & Rosa, 2007). Apart from coverage pressure, departmental climate has the potential to be acutely influential. As reported by Henderson and Dancy (2007), working with colleagues who either lack knowledge about, or withhold support of, pedagogical reform inhibits an instructor's willingness to modify current practice. On the other hand, at institutions where collegiality and open communication is the norm, instructors not only have the opportunity for exposure to a range of strategies and pedagogical techniques from their colleagues, but also the safe space in which to attempt this non-traditional pedagogy. Thus, perceived notions concerning departmental expectations, lack of support from colleagues or supervisors, and a lack of common vision for reform among the faculty (Henderson & Dancy, 2007, Roth McDuffie & Graeber, 2003) collectively factor significantly when instructors plan courses.

Collectively these studies illustrate that the pedagogical decision-making of mathematics faculty is quite complicated. While there is adequate evidence of the effectiveness and appropriateness of student-centered approaches, the practical implementation of such techniques is affected by a range of factors related to collegial support, promotion and tenure considerations, course coordination, and class size. To that end, the present research investigates the teaching practices of university Calculus instructors and the effects of the aforementioned influences therein. Specifically, the following research questions are investigated: Are calculus instructors employing more active-learning methods or teacher-centered practices in their courses? Can this be explained by class size, number of class sections, or departmental support for innovative teaching?

Methods

The present study is situated within the larger research project entitled Characteristics of Successful Programs in College Calculus (CSPCC) that was designed to gain a nationwide overview of the college calculus programs across the US, as well as to identify more successful programs based on a combination of factors including: grades, affective variables (e.g., interest, enjoyment, and confidence), and intention to continue on to Calculus II (for more information on the CSPCC project, please see Bressoud, Mesa, & Rasmussen, 2015). The CSPCC project used a stratified random sample of colleges and universities in the U.S. based on the highest degree granted at each university (Associate's, Bachelor's, Master's, or Ph.D.). The first phase was comprised of a total of six surveys: three for the students (one at the beginning of Calculus I, one at the end of Calculus I, and one a year later to the students that gave their email addresses), two for the instructors (one at the beginning of Calculus I and one at the end of Calculus I), and one survey given to the Calculus course coordinator. For the purposes of this study, we limited our dataset to those instructor respondents who had completed the end of semester survey. In total, there were 490 instructors distributed across 160 institutions (average cluster size of n = 3.06). The nested nature of our data causes us to consider reports of these variables at both the instructor and institutional levels and investigate effects at each, thus allowing us to investigate the influence of institutional context on individual decision-making while remaining cognizant of the fact that an individual's perception may not be indicative of the departmental context at large.

For each instructor, three variables were considered: class size, perception of support, and a composite teaching practice (CTP) score. Class Size was measured as the number of students enrolled in the course at the end of the term. Perception of Support was measured using the following survey item: "From your point of view, how supportive is your department for implementing innovative approaches to teaching Calculus I? on a 4-point Likert scale (1 = not supportive, 4 = very supportive)." The CTP score was determined based on self-reported teaching practices on a series of eight 6-point Likert scale (1 = *not at all*, 6 = *very often*) items measuring their frequency of occurrence. Each of the items was classified as being teacher-centered or student-centered on the basis of who was doing the mathematical work. See Table 1 for details.

TP1, TP6, and TP7 were averaged to obtain the teacher-centered (TC) score; TP2, TP5, and TP8 were averaged to obtain the student-centered (SC) score. TP3 was considered to be a somewhat neutral practice as this can theoretically involve both the teacher and the students doing mathematical work and was thus removed from consideration for the composite. TP4 is certainly a student-centered practice; however, this practice has the potential to be a one-shot opportunity in an otherwise lecture-dominated course. For this reason, and also the fact that a very small percentage of respondents indicated any use of this practice, TP4 was removed from consideration. The CTP was obtained by subtracting the TC score from the SC score. In this way, teaching practices have been condensed into a unidimensional measure where positive scores indicate a tendency towards student-centered practices and negative scores towards teacher-centered ones.

For each institution, four variables were considered, three of which were aggregate measures of instructor-level variables: class size, perception of support, and CTP. The only institution-level characteristic was that of course coordination. Not having a way to measure this directly (i.e. knowledge of common delivery methods, common HW assignments, etc.), this was measured indirectly. Operating under the assumption that multiple sections of the same course often necessitates course coordination, and that this need might increase as do the number of sections, the number of sections of Calculus I being offered at that institution for the time period under investigation was used as a proxy for course coordination; however, we acknowledge that this is not an ideal measure for coordination.

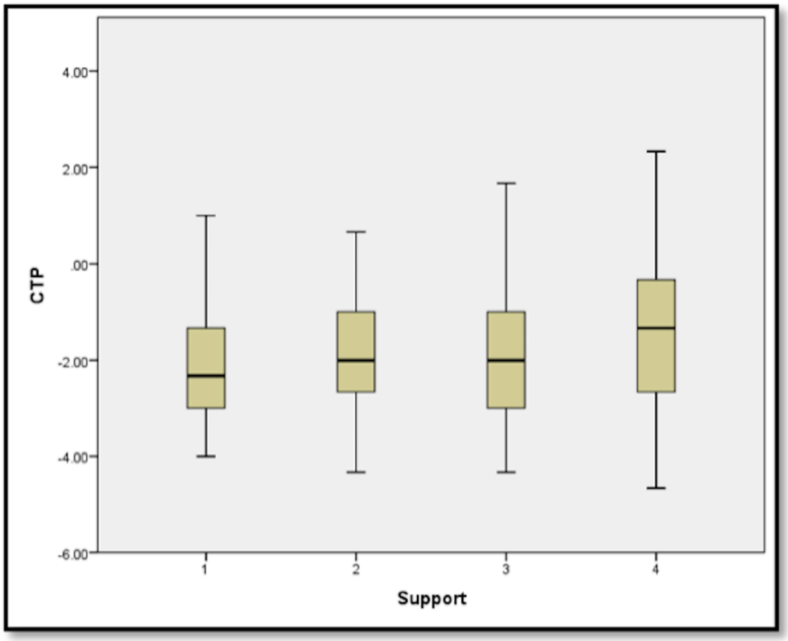
Table 1
Classification of teaching practices items

Item	Prompt	SC	TC	Omit
TP1	Show students how to work specific problems		x	
TP2	Have students work with one another	x		
TP3	Hold a whole-class discussion			x
TP4	Have students give presentations			x
TP5	Have students work individually on problems or tasks	x		
TP6	Lecture		x	
TP7	Ask questions		x	
TP8	Ask students to explain their thinking	x		

Table 2
Univariate Descriptive Statistics

	Instructor Level			Institution Level			
Statistic	Class Size	Support	CTP	Class Size_Mean	Support_Mean	CTP_Mean	# Sections
Minimum	6	1	-4.67	8	1	-4.33	1
Maximum	321	4	2.33	321	4	0.67	52
Mean	41.97	2.879	-1.799	45.7126	2.8949	-1.8897	7.3563
St. Dev.	41.424	0.8696	1.3511	50.76861	0.68075	7.3563	7.16767

Figure 1
CTP score as a function of perceived departmental support



To inform the model, descriptive statistics were computed at both the univariate and bivariate levels. The univariate analysis provided descriptive statistics for each of our variables of interest. The bivariate analysis investigated the relationship between the independent and dependent variables to inform which, if any, should be included in the model. The research questions were then analyzed with a multi-level modeling approach using *HLM for Windows* software (version 7.26b, Raudenbush, Byrk, & Congdon, 1996-2015).

Results

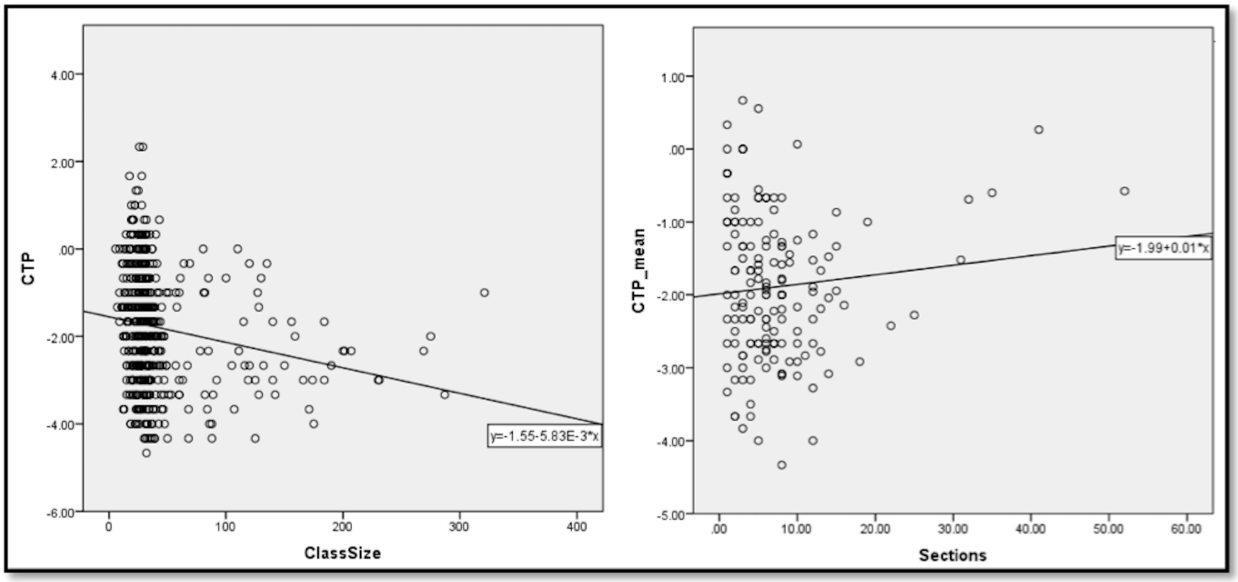
Descriptive Statistics

The initial univariate analysis (see Table 2) revealed that the participating institutions were quite disparate in terms of the number of students being served, both in terms of students per class and number of sections per term. On average, instructors are reporting more teacher-centered practices than student-centered methods. While not surprising based on the extant literature, this is particularly interesting in this study because this predilection for teacher-centered practice (mean CTP = -1.8) exists despite promising perceptions of departmental support for innovative teaching (72.1% of instructors rate support as a 3 or 4 on the 4-point scale).

The initial bivariate analysis focused on the correlations between the variables under investigation. (Complete correlation matrices can be found in Appendix A.) There is reason to believe that both perceived support and class size have the potential to influence an instructor's pedagogical decision-making, and the data did corroborate this. At the instructor level there was a statistically significant positive correlation between perception of departmental support and CTP ($r = .131$, $p = .004$; see Figure 1); similarly, there was a

Figure 2

Scatterplots of CTP as a function of class size and number of sections



statistically significant negative correlation between class size and CTP ($r = -.179$, $p < .001$; see Figure 2). Both of these findings are consistent with the extant literature. At the institutional level, these correlations paralleled those at the instructor level; however, only the class size relationship was statistically significant ($r = -.19$, $p = .016$). Interestingly, there appeared to be a positive relationship between number of sections (our coordination proxy) and mean CTP score by institution, suggesting that coordination is functioning as an organized effort to employ student-centered approaches across multi-section courses; although, this failed to be statistically significant (see Figure 2).

HLM Analysis

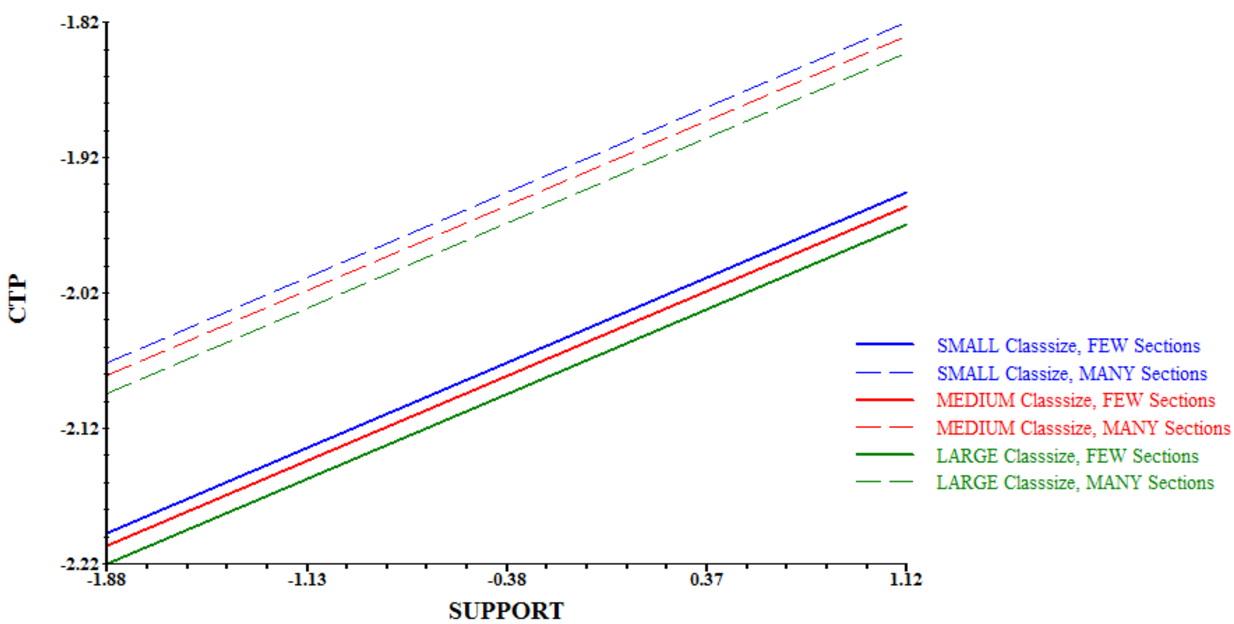
The multi-level modeling began with the unconditional model. In this model, we are able to estimate the mean CTP score and determine the suitability of the data for a hierarchical model. From this model, we were able to conclude that instructors are employing more teacher-centered practices (based on the mean CTP score of -1.91) and that a hierarchical model is appropriate for this dataset ($\chi^2 = 336.32592$, $df = 157$, $p < .001$), with approximately 24% of the variance in CTP scores attributable to between-school variation (ICC = .2446). In order to explain this behavior, two independently run model sets were estimated – one each for departmental support and class size – in which the predictors were analyzed at both the instructor and institutional level. Details for each of the sub-models can be found in Appendix B.

Looking at the effect of Support on CTP, there is a positive relationship between perceived level of support and use of student-centered teaching practices. This effect is seen at both the instructor and institutional levels; however, this is only significant at the institutional level ($\gamma_{01} = .252128$, $p = .045$). In practical interpretation, the observed result would imply that for every one-unit increase in support by institution, an instructor's CTP score will improve by .25 on average.

Looking at the effect of Class size on CTP, there is a negative relationship between the number of students and the use of student-centered teaching practices. This effect is seen at both the instructor and institutional levels; however, this is again only significant at the institutional level ($\gamma_{01} = -.004788$, $p = .003$). In practical interpretation, the observed result would imply that for every one-unit increase in average class size by institution, an instructor's CTP score will decrease by .004 points on average. This might seem like an inconsequential amount, but remember that a one-unit change in class size is not comparable to a one-unit change in support. With class sizes ranging from 6 to 321, it might be more appropriate to consider this coefficient in terms of 10-student increases (.04) or 100-student-increases (.4) as a more practical interpretation.

After considering sub-models for each main independent variable, the effects observed were used to inform a multi-predictor model in which the effects of Class Size and Support were considered simultaneously. The initial analysis made a fixed slopes assumption. In the combined model, the viability of a variable slopes model was investigated.

Figure 3
Graph of model equations at the institutional level



An iterative model-building procedure was used in which a deviance test was performed between iterations to determine suitability for parameter removal. These details can be found in Appendix C.

The final model retained the number of sections (SECTIONS), average class size (meanCLASSIZ) and typical perception of support (meanSUPPORT) at the institutional level and class size (CLASSIZ) and individual perception of support (SUPPORT) at the instructor level. The model estimated fixed slopes for class size and variable slopes for support at the instructor level. The final model equations, as well as the parameter estimates, can be found in Appendix D.

We can see that at the institutional level, increasing the number of sections has a positive effect (i.e. teacher behavior becomes more student-centered), as does increasing support for implementation of innovative teaching practices, whereas increasing class size has a negative effect. This result is well-captured in Figure 3[1] where the dotted lines (representing institutions with many sections) universally outrank the solid lines (representing institutions with few sections), and within each grouping the average CTP score rises as class size decreases from large to medium to small. All model equations have positive slope, demonstrating the universal effect that increased support has on CTP – independent of class size and coordination.

At the instructor level, we see similar effects: increasing an instructor's class size relative to the institutional average has a negative effect, and increased perception of support relative to the institutional average has a positive effect. It is important to note, however, that with the variable slopes model, the effect of support can vary considerably among instructors, and while typically this has a positive effect, the range of possible values (-.584, .751) indicates that the effect of an instructor's discrepancy between perceived support and the institutional average can influence the instructor in either the student-centered or teacher-centered directions. In other words, the effect is not universal for individual instructors.

Discussion

Overall, the effects of class size and support are functioning as the literature would suggest. Here we highlight three specific examples. Firstly, increased class sizes negatively impact the use of student-centered pedagogy. Secondly, supportive departments

[1] Note that the CLASSSIZ designations refer to the 25th/50th/75th percentiles for Small/Medium/Large respectively; Similarly, the SECTIONS designations refer to the 25th/75th percentiles for FEW/MANY respectively.

(as measured by the average of the instructor reports) are indeed increasing the amount of student-centered instructional practices on the average, even though the impact on individual instructors may vary. Finally, having multiple sections of the course taught at the same institution increases the amount of student-centered instruction, regardless of the size of those courses. This suggests that coordination may be a powerful influence on instructional practice.

What is interesting about these results is that these effects are more salient at the institutional level as compared with the instructor level. Taken together, these findings highlight the importance of institutional context (e.g., the average experience of individuals within a department) over the context experienced by individuals. These findings provide large-scale empirical support for several interview studies that have identified the importance of situational characteristics such as supportive administrators (e.g., Foote, Knaub, Henderson, Dancy, & Beichner, 2016; McDuffie & Graeber, 2003), class size and room layout (e.g., Henderson & Dancy, 2007; McDuffie & Graeber, 2003), and department norms (e.g., Henderson & Dancy, 2007).

Further, this research suggests that change strategies might be more effectively administered with support through the department chair and/or course coordinators as opposed to targeting individual instructors through professional development opportunities. These administrators may have some influence on factors like class size and the number of sections (which in turn may necessitate the need for coordination). Even in cases where these variables are outside of their control, chairs and coordinators can provide support for innovative teaching practices, including how such teaching behaviors would be viewed in light of tenure/promotion decisions. Alternatively, faculty could themselves foster a supportive environment for instructional change.

This study, while promising, has several limitations that must be addressed. Firstly, the level of coordination was only measured using the number of course sections as a proxy. The use of extant data made it hard to reliably measure this variable, but future research could gather data specific to this objective. Secondly, the cluster size is quite low for current recommendations. Fifty-one institutions only reported data for a single instructor, and the average was a mere 3.06 instructors/institution. Finally, the use of the CTP composite is controversial. Assuming that teaching practices can be reduced to a single dimension (student-centered to teacher-centered continuum) is probably overly simplistic and possibly unrealistic. Preliminary multi-dimensional scaling results indicate that this might better be modeled as a 2-dimensional construct. Future research would investigate this further and would aim to construct a better composite measure of teaching practices.

Conclusion

Our analysis of this national data, gathered from 490 instructors distributed across 160 institutions, provides three main findings and implications. First, the findings of this research provide large-scale empirical support for several interview studies that have identified the importance of situational characteristics and highlight the importance of institutional context as related to individual pedagogical decisions. The results of this research suggest that the decision to implement student-centered pedagogy, and the degree of implementation therein, is affected by class size, departmental support, and level of course coordination. The use of teacher-centered instructional approaches decreases, on average, as class sizes decrease and departmental support and level of course coordination increase.

Second, our analysis was able to determine that the effects of class size and departmental support on instructional practice are more salient at the institutional level. An interpretation of this finding, for instance, would be that an individual's instructional practice seems to be more influenced by the average class size in the department than by the class size of his or her individual course. Or put another way, instructors who teach *the only* small class (in a department with routinely large classes) are less likely to use student-centered instructional practices than an instructor in a department that routinely keeps class sizes small. A possible implication of this result is the consideration of the effect departmental culture (including instructional norms) has on individual decision-making, namely, that a department offering many small sections may be indicative of a culture that supports, facilities, and expects good teaching.

Finally, our finding that institutional level variables are more influential than individual level variables suggests that instructional reform efforts aimed at department chairs and course coordinators might be more successful than those developed for individual instructors (e.g., professional development designed to disseminate best practices). Individual instructors can do little to decrease class size, increase departmental support for innovative teaching, and increase coordination. Furthermore, even if individuals were able to get these changes for themselves, the impact of such changes is likely to be limited if implemented in a department where this goes against the status quo. Our findings suggest that we see the strongest reports of student-centered instruction in departments where these supports and resources are the norm, and it would be remiss not to consider the influence the department chairs and course coordinators have in establishing that departmental culture.

References

Benton, S., & Pallett, W. (2013). Class size matters. *InsideHigherEd*. Retrieved from https://www.insidehighered.com/views/2013/01/29/essay-importance-class-size-higher-education

Bressoud, D., Mesa, V., & Rasmussen, C. (2015). *Insights and recommendations from the MAA National Study of Calculus*. Washington, DC: Mathematical Association of America.

Daempfle, P. A. (2003). An analysis of the high attrition rates among first year college science, math, and engineering majors. *Journal of College Student Retention: Research, Theory & Practice*, *5*(1), 37-52.

Eagan, K. (2016). *More student-centered? An examination of faculty teaching practices across STEM and non-STEM disciplines between 2004 and 2014.* Los Angeles, CA: Higher Education Research Institute.

Foote, K., Knaub, A., Henderson, C., Dancy, M., & Beichner, R. J. (2016). Enabling and challenging factors in institutional reform: The case of SCALE-UP. *Physical Review Physics Education Research, 12*(1), 010103-1 - 010103-22.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Science, 111*(23), 8410-8415.

Fukawa-Connelly, T. P., & Newton, C. (2014). Analyzing the teaching of advanced mathematics courses via the enacted example space. *Educational Studies in Mathematics*, *87*(3), 323-349.

Gerdes, H., & Mallinckrodt, B. (1994). Emotional, social, and academic adjustment of college students: A longitudinal study of retention. *Journal of Counseling and Development: JCD*, *72*(3), 281-288.

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics-Physics Education Research, 3*(2), 020102-1 - 020102-14.

Hurtado, S., Eagan, M. K., & Chang, M. (2010). *Degrees of success: Bachelor's degree completion rates among initial STEM majors.* Retrieved from http://www.heri.ucla.edu/nih/downloads/2010%20%20Hurtado,%20Eagan,%20Chang%20-%20Degrees%20of%20Success.pdf

Jaworski, B., Treffert-Thomas, S. & Bartsch, T. (2009). Characterising the teaching of university mathematics: A case of linear algebra. In M. Tzekaki., M. Kaldrimidou & C. Sakonidis, (Eds.), *Proceedings of the 33rd Conference of the International Group for the Psychology of Mathematics Education* (pp. 249-256). Thessaloniki, Greece: PME.

Johnson, E. (2013). Teacher's mathematical activity in inquiry-oriented instruction. *Journal of Mathematical Behavior. 32*(4)*,* 761-775. doi:10.1016/j.jmathb.2013.03.002

Lew, K., Fukawa-Connelly, T. P., Mejía-Ramos, J. P., & Weber, K. (2016). Lectures in advanced mathematics: Why students might not understand what the mathematics professor is trying to convey. *Journal for Research in Mathematics Education*, *47*(2), 162-198.

Olson, S., & Riordan, D. G. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the President.* Washington, DC: Executive Office of the President.

Rasmussen, C., & Ellis, J. (2013). Who is switching out of calculus and why? In A. M. Lindmeier, & A. Heinze (Eds.), *Proceedings of the 37th Conference of the International Group for the Psychology of Mathematics Education* (pp. 73-80). Kiel, Germany: PME.

Rasmussen, C., & Ellis, J. (2015). Chapter 9: Calculus coordination at PhD-granting universities: More than just using the same syllabus, textbook, and final exam. In D. Bressoud, C. Rasmussen & V. Mesa (Eds.), *Insights and recommendations from the MAA National Study of Calculus* (pp. 107-116)*,* Washington, DC: Mathematical Association of America.

Raudenbush, S. W., Bryk, A. S., & Congdon, R. (1996-2015). *HLM for Windows* [Computer software]. Skokie, IL: Scientific Software International, Inc.

Roth McDuffie, R., & Graeber, A. (2003). Institutional norms and policies that influence college mathematics professors in the process of chaging to reform-based practices. *School Science and Mathematics*, *103*(7), 331-344.

Selinski, N., & Milbourne, H. (2015). Chapter 3: The institutional context. In D. Bressoud, C. Rasmussen & V. Mesa (Eds.), *Insights and recommendations from the MAA National Study of Calculus* (pp. 31-44)*,* Washington, DC: Mathematical Association of America.

Seymour, E. (2006). *Undergraduate science, math, and engineering education: What's working?* Testimony offered to the Research Subcommittee of the Committee on Science of the US House of Representatives Hearing on Undergraduate Science, Math and Engineering Education, Washington, DC.

Thompson, P. W., Castillo-Chavez, C., Culbertson, R., Flores, A., Greeley, R., Haag, S., et al. (2007). *Failing the future: Problems of persistence and* *retention in science, technology, engineering, and mathematics majors at Arizona State University. Arizona State University Provost Office Report*. Tempe, AZ: Arizona State University.

Tinto, V. (1999). Taking retention seriously: Rethinking the first year of college. *NACADA Journal*, *19*(2), 5-9.

van Langen, A., & Dekkers, H. (2005). Cross-national differences in participating in tertiary science, technology, engineering and mathematics education. *Comparative Education*, *41*(3), 329-350.

Wagner, J., Speer, N., & Rossa, B. (2007). Beyond mathematical content knowledge: A mathematician's knowledge needed for teaching an inquiry-oriented differential equations course. *Journal of Mathematical Behavior*, *26*(3),247-266.

Weber, K. (2004). Traditional instruction in advanced mathematics courses: A case study of one professor's lectures and proofs in an introductory real analysis course. *The Journal of Mathematical Behavior*, *23*(2), 115-133.

Yoshinobu, S., & Jones, M. (2012). The coverage issue. *PRIMUS, 22*(4), 303-316.

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Appendix A

Correlation Matrices by Instructor and Institution

Correlation Matrix for all Indicators at the Institution Level

Indicator	1	2	3	4
1. Sections	-			
2. ClassSize_Mean	-.061	-		
3. Support_Mean	-.084	-.102	-	
4. CTP_Mean	.094	-.190*	.090	-

Note: * Correlation is significant at the 0.05 level (2-tailed).

Correlation Matrix for all Indicators at the Instructor Level

Indicator	1	2	3
1. ClassSize	-		
2. Support	-.138**	-	
3. CTP	-.179**	-.131**	-

Note: ** Correlation is significant at the 0.01 level (2-tailed).

Appendix B

Details of Sub-Models for Support and Class Size

Submodel Statistics & Parameter Estimates

Model	Fixed Effects			Variance Components			
SUPPORT	g_{00} (se)	g_{01} (se)	g_{10} (se)	s^2		t_{00}	
Unconditional	-1.91 (.08)	N/A	N/A	1.31392	(Base)	0.42549	(Base)
Means as Outcomes	-1.90 (.08)	.25 (.13)	N/A	1.32903	-0.0115	0.3935	0.07518
1-Way ANCOVA	-1.91 (.08)	N/A	.118 (.08)	1.3178	-0.003	0.40522	0.04764
GroupMean Center Model	-1.91 (.08)	N/A	.065 (.09)	1.31516	-0.0009	0.42521	0.00066
Traditional Compositional Effects model	-1.90 (.08)	.25 (.13)	.065 (.09)	1.32219	0.00629	0.3932	0.07589

Model	Fixed Effects			Variance Components			
CLASSSIZE	g_{00} (se)	g_{01} (se)	g_{10} (se)	s^2		t_{00}	
Unconditional	-1.91 (.08)	N/A	N/A	1.31392	(Base)	0.42549	(Base)
Means as Outcomes	-1.91 (.08)	-.004(.002)	N/A	1.31658	-0.002	0.38258	0.10085
1-Way ANCOVA	-1.9 (.08)	N/A	-.004 (.001)	1.31575	-0.0014	0.38648	0.09168
GroupMean Center Model	-1.9 (.08)	N/A	-.002 (.003)	1.316	-0.0016	0.42501	0.00113
Traditional Compositional Effects model	-1.91 (.08)	-.004 (.001)	-.002 (.003)	1.31866	-0.0036	0.38211	0.10195

Appendix C

Model-Building Details

Model Building Deviance Testing Details

			Deviance	df	p-value
		Level 1 Model Building			
Model	Level 1 Variables	Comments			
Model 1	CLASSIZ & SUPPORT (group centered)	all slopes random at Level 2	1584.62	10	
Model 2	CLASSIZ & SUPPORT (group centered)	slope for SUPPORT random (μ2j), CLASSSIZ fixed (μ1j)	1588.2	5	0.611
		Level 2 Model Building			
Model	Level 1 Variables	Comments			
Model 3	CLASSIZ & SUPPORT (group centered)	CLASSSIZ_Mean & SUPPORT_Mean (grand centered for β0j and β2j)	1575.63	11	
Model 4	CLASSIZ & SUPPORT (group centered)	Remove CLASSSIZ_Mean & SUPPORT_Mean from β2j	1575.75	9	0.9404
		Adding Covariates			
Model	Level 1 Variables	Comments			
Model 5	CLASSIZ & SUPPORT (group centered)	Add SECTIONS to β0j grand mean centered	1566.69	10	0.0026

Appendix D

Parameter Estimates & Model Equations

Final Estimation of Fixed Effects:

Fixed Effect	Coefficient	Standard Error	*t*-ratio	Approx. *df*	*p*-value
For INTRCPT1, $\beta 0$					
INTRCPT2, $\gamma 00$	-1.958325	0.072474	-27.021	154	<0.001
SECTIONS, $\gamma 01$	0.025163	0.007571	3.324	154	0.001
CLASSSIZ, $\gamma 02$	-0.00388	0.001682	-2.307	154	0.022
SUPPORT, $\gamma 03$	0.232043	0.116565	1.991	154	0.048
For CLASSSIZ slope, $\beta 1$					
INTRCPT2, $\gamma 10$	-0.001625	0.003388	-0.48	163	0.632
For SUPPORT slope, $\beta 2$					
INTRCPT2, $\gamma 20$	0.083439	0.093472	0.893	157	0.373

Final Estimation of Variance Components:

Random Effect	Standard Deviation	Variance Component	*df*	$\chi 2$	*p*-value
INTRCPT1, $\mu 0$	0.51057	0.26068	87	178.0211	<0.001
SUPPORT slope, $\mu 2$	0.34036	0.11585	90	108.5163	0.089
level-1, r	1.13426	1.28655			

$$\widehat{CTP} = \widehat{\gamma_{00}} + \widehat{\gamma_{01}} * \left(SECTIONS_j - \overline{SECTIONS}\right) + \widehat{\gamma_{02}} * \left(meanCLASSSIZ_j - \overline{meanCLASSSIZ}\right) + \widehat{\gamma_{03}} * \left(meanSUPPORT_j - \overline{meanSUPPORT}\right) + \widehat{\gamma_{10}} * \left(CLASSIZ_{ij} - \overline{CLASSSIZ._j}\right) + \widehat{\gamma_{20}} * (SUPPORT_{ij} - \overline{SUPPORT._j})$$

$$\widehat{CTP} = -1.958 + .025 * \left(SECTIONS_j - \overline{SECTIONS}\right) - .00388 * \left(meanCLASSSIZ_j - \overline{meanCLASSSIZ}\right) + .232 * \left(meanSUPPORT_j - \overline{meanSUPPORT}\right) - .00163 * \left(CLASSIZ_{ij} - \overline{CLASSSIZ._j}\right) + .083 * (SUPPORT_{ij} - \overline{SUPPORT._j})$$

For an instructor teaching at a school with the typical number of sections, the typical average class size, and the typical mean departmental support, this equation reduces to:

$$\widehat{CTP} = \widehat{\gamma_{00}} + \widehat{\gamma_{10}} * \left(CLASSIZ_{ij} - \overline{CLASSSIZ._j}\right) + \widehat{\gamma_{20}} * (SUPPORT_{ij} - \overline{SUPPORT._j})$$

$$\widehat{CTP} = -1.958 - .00163 * \left(CLASSIZ_{ij} - \overline{CLASSSIZ._j}\right) + .0834 * (SUPPORT_{ij} - \overline{SUPPORT._j})$$