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Carla van de Sande, Mark Reiser
Arizona State University

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Abstract

Summer break sets students in grades K-12 back by at least one month of instruction and has the strongest impact on mathematics retention. This study investigates whether there is evidence of the summer gap effect at the university level for engineering students enrolled in the introductory calculus course sequence, and possible demographic mediators. Five years of final course grades for students who took the summer off between the first two courses in the Introductory Calculus for Engineers course sequence were compared with grades of students who took both courses in the same academic year. An analysis of covariance and an analysis of difference scores were used to examine the effect of summer break on grades in Calculus 2 and to control for time-invariant characteristics, including aptitude. Results show that university students who take the summer off lose the equivalent of about half a course grade more than do students who take the two courses in the same academic year. The summer break has the most impact on the strongest students, suggesting that it may contribute to the loss of many talented engineering majors. Gender does not mediate the summer gap effect, although international students outperform students who are US citizens.

Introduction

The motto "use it or lose it" succinctly captures the sad reality of what happens over time to skills and capabilities that are not practiced. Examples of the positive effects of cognitive engagement over time, and the corresponding negative effects of disengagement, come from studies of aging (Rohwedder & Willis, 2010), as well as from seminal work in educational psychology on memory and learning (Ebbinghaus, 1964). Indeed, the ability to retain knowledge can be thought of as one of the cornerstones of education since knowledge and understanding are useless unless they can be remembered and applied.

The School Calendar in K-12 Education

In school, students must not only remember what they learn throughout the year, but they must also retain what they have learned from one year to the next. However, the traditional 9-month school calendar, in which schools open their doors in the fall and then close them during the summer months, was not designed with this purpose in mind (Gold, 2002). Historically, the inclusion of a three-month summer break met the needs of a society in which many families' schedules were tied to the agriculture cycle and in which air-conditioned school buildings were not the norm. Over time, a significant decrease in the number of families involved in agriculture and an increase in the ability to provide comfortable temperatures in classrooms made these considerations no longer relevant. However, the summer-off calendar remained the norm in U.S. schools for many years. It was not until the 1980's that alternative school calendars became the focus of widespread interest and attention, due in part to research showing how a lengthy summer gap affects student achievement (Barrett, 1990; Harris & Wallace, 2012; Skinner, 2014).

Prior to 1975, many studies, covering a range of different school grades and subject areas, found that summer vacation has a detrimental effect on student achievement (Cooper et al., 1996). A meta-analysis of 13 studies reported after 1975 corroborated these findings, and, furthermore, quantified the effect of summer vacation on standardized test scores (Cooper, 2003; Cooper et al., 1996). By a conservative estimate, summer vacation sets students back by one month of instruction, that is, it causes them to lose one month of grade-level equivalent skills relative to national norms. The meta-analysis also revealed differences in the way summer vacation affects different school subjects and skill areas. A lengthy summer break has a greater detrimental impact on mathematics than on reading or language, perhaps because students have more opportunities (Murname, 1975) and motivation (Geary, 1995) to read and learn new vocabulary during the summer than they have to practice and learn mathematics. Within mathematics, summer loss has the most effect on skills areas that rely heavily on knowing facts and performing procedures since these types of knowledge fade quickly in the absence of sustained practice (Cooper, 1989).

The Academic Calendar in Post-secondary Education

Despite the growing push to restructure the K-12 school calendar to address summer learning loss, most college academic calendars remain patterned after the traditional 9-month school calendar. Although alternative systems (e.g., quarters or trimesters) are used by some colleges, the semester system, that partitions the academic year into two 15-week sessions followed by a 3-month summer break, was used by 75% of colleges in 1930 (James, 1930) and remains the most popular academic calendar today (Smith, 2012).

The bulk of instruction thus takes place during the fall and spring semesters, although colleges may offer a limited selection of courses over the summer in an abbreviated amount of time. For instance, a 15-week semester course that meets 3 hours weekly in an academic year may be offered during the summer as a 6-week course that meets 7.5 hours weekly. However, even though many higher education institutions now offer high-demand courses during the summer, many students elect not to take them. For instance, at the university where this study was conducted, approximately 80% of students who take the first course of an engineering mathematics course sequence in the spring semester wait until the fall semester to take the second course in the sequence, putting a large summer gap between these two closely related courses.

The Role of Introductory Calculus Instruction

Many students enter university with dreams of receiving a STEM degree, but then are forced to abandon their dreams and switch to other majors. In fact, fewer than 40% of students fulfill their initial intent of completing a STEM degree, and a recent study found that one reason that students departed from STEM majors was their failure to succeed as well as they expected in required courses (Klobuchar, 2014). For engineering majors, the introductory calculus course sequence is one such requisite. This course sequence is intended to be taken during freshman year which is a critical time for student success and persistence in engineering (Moller-Wong & Eide, 1997). Thus, success in introductory calculus can be pivotal for completion of an engineering degree (Veenstra, Dey, & Herrin, 2009).

Research Questions

Given the widespread adoption of the semester system and its similarity to the 9-month school calendar, *the main research question that this study addressed was whether the summer gap effect that has been well documented in grades K-12 is also in evidence at the university level*. We chose to focus our attention on student success in the introductory calculus course sequence for engineering students for several reasons.

First, procedural mathematical knowledge is most affected by the summer gap in grades K-12, making introductory calculus for engineering students with its focus on skills and applications a logical place to search for a university summer gap effect. Second, introductory calculus instruction consists of a sequence of closely related courses, so that the content of the second courses builds directly on the content of the first course. Retention of the content learned in the first course is critical for success in the second course. Third, the introductory calculus course sequence may be taken within a single academic year or across academic years, an option that is selected by many students. These students must then retain relevant and requisite knowledge and skills from the first course over a 3-month long summer break.

Finally, introductory calculus is critical for success and retention in engineering programs. Students need to pass the introductory calculus course sequence in order to enroll in more advanced mathematics and engineering courses. In keeping with the K-12 research, a secondary research question was whether individual differences, such as gender and ethnicity, play a role as potential moderating influences of the summer gap effect at the university level.

Methods

Participants

Participants were undergraduate students at a large Southwestern university who enrolled in the first two courses in the Introductory Calculus for Engineers sequence in a single academic year (Straight Through) or with an intervening summer term (Summer Off), beginning in the 2010 academic year. Only students enrolled for a grade in face-to-face courses were included in our sample since online sections have different course grade criteria and include some unproctored exams. Table 1 shows the number of Straight Through (ST) and Summer Off (SO) students for the five academic years for which data was collected.

Table 1. Number of participants by academic year and summer off status

	Academic Year				
Summer Off Status	2010	2011	2012	2013	2014
ST	451	611	751	717	665
SO	174	166	234	249	201

The average percentage of female ST students across academic years was 18.1%, slightly higher than the average percentage of female SO students which was 17.3%. The majority of students were either freshman or sophomores, with an average percentage of 91.4% for ST students and 80.3% for SO students across academic years. Table 2 shows the average percentage of students by self-reported ethnicity across all academic years; the category “Other” includes Native American and Alaska Native, Black and African American, Native Hawaiian and other Pacific Islander, and students reporting multiple ethnicities, and “Not Reported” refers to international students who did not report their ethnicity.

Table 2. Ethnicity of participants by summer off status across years

	Academic Year				
Summer Off Status	White	Hispanic	Asian	Other	Not Reported
ST	51.0%	18.6%	9.5%	8.4%	12.4%
SO	43.7%	20%	5.9%	8.9%	21.4%

The course sequence

Calculus 1 and Calculus 2 are the first two courses in the Introductory Calculus for Engineers course sequence and are required for all engineering majors, as well as for some liberal arts majors. Calculus 1 includes topics such as limits and continuity, techniques and applications of differentiation, and an introduction to integration. The sequential course, Calculus 2, covers topics including techniques and applications of integration, sequences and series, and parametric equations. Both of these courses require students to master numerous procedures and skills, and many of the procedures taught in Calculus 2 build directly on those learned in Calculus 1. For instance, in order to find Taylor series approximations in Calculus 2, students must use their Calculus 1 knowledge of the techniques for finding derivatives. Thus, not only is successful completion of Calculus 1 (in terms of final course grade) a pre-requisite for enrolling in Calculus 2, but success in Calculus 2 hinges heavily on the retention of skills and procedures taught in Calculus 1. Both Calculus 1 and Calculus 2 are offered in face-to-face courses over 15 weeks (plus final exams) in fall and spring semesters. Although several sections of each course are taught during the same semester by different instructors, the sections are coordinated so that each section follows the same curriculum and has similar homework assignments and exams. Course grades are calculated on raw percentages, rather than curved.

Data

For each of the five academic years, we collected the final course grades for students who were enrolled in all face-to-face sections of Calculus 1 and Calculus 2, the first two courses in the Introductory Calculus for Engineers course sequence. We therefore had paired Calculus 1 and Calculus 2 course letter grades for two student cohorts in each year: ST students who took both courses within a single academic year, and SO students who had an intervening summer term between the two courses. Course letter grades range from E to A+, and a grade of W is given to students who withdraw from a course before a specified deadline. A grade of C or above in Calculus 1 is a prerequisite for enrollment in Calculus 2. For the purpose of analysis, these letter grades were converted to numeric scores on the scale of 0 to 4.33, with grades of W assigned a numeric score of 0. We also had access to self-disclosed declarations of gender and ethnicity.

Modeling

In addition to comparing percentages of successful completion of Calculus 2 and tracking the Calculus 2 performance of students who were most successful in Calculus 1, we used two statistical models, analysis of covariance and analysis of difference scores, to examine the effect of the summer gap on grades in Calculus 2. Because allocation of students to treatments (ST vs. SO) is not random, the analysis of covariance and the analysis of difference scores have different interpretations regarding the effect of the summer gap. The analysis of covariance model is given by

$$Y_{ijklrs2} = \beta_0 + \beta_1 Y_{ijklrs1} + \alpha_j + \gamma_k + \psi_l + \zeta_r + \upsilon_s + \epsilon_{ijklrs2}$$

where $Y_{ijklrs2}$ is Calculus 2 course grade, xxx is Calculus 1 course grade, α_j is a fixed-effect for summer-off status (ST vs. SO), γ_k is a fixed-effect for year *k*, ψ_l is a fixed-effect for gender *l*, ζ_r is a fixed-effect for ethnicity *r*, υ_s is a random effect for Calculus 2 class section *s* (*i.e.* instructor), and $\epsilon_{ijklrs2}$ is random error. It is assumed that $\upsilon_s \sim N(0, {\sigma_\upsilon}^2)$ and $\epsilon_{ijklrs2} \sim N(0, {\sigma_\varepsilon}^2)$, independent of υ_s. The model implies that measurements on students within the same class section of Calculus 2 are correlated but measurements across different sections and across years are independent. The test of the summer gap effect controls for Calculus 1 course grade, year, ethnicity and gender. Since the model includes both fixed and random effects, it is known as a mixed model. Since students are nested within classroom sections, it is also known as a nested-error model.

The test of the summer-gap effect in the analysis of covariance described above controls for Calculus 1 course grade, year, ethnicity, and gender, but there are many student-level time-invariant covariates for which it does not control. In particular, it does not control for mathematics aptitude. A covariate such as SAT score could be used to attempt to control for mathematics aptitude, but this type of covariate was not available. So, we turn to difference scores, which are commonly used in econometric applications because they remove the effect of time-invariant covariates such as student aptitude.

At timepoint 1, which would be the time at which a student takes Calculus 1, the regression of calculus grade on aptitude for student *i* would be $Y_{i1} = {\beta_0}^{(1)} + \beta_1 X_i + \epsilon_{i1}$, where X_i is a time-invariant covariate such as student aptitude. At timepoint 2, which would be the time at which student *i* takes Calculus 2, the regression of calculus grade on aptitude would be $Y_{i2} = {\beta_0}^{(2)} + \beta_1 X_i + \epsilon_{i2}$. Then the difference score, D_i, is given by $D_i = Y_{i2} - Y_{i1} = {\beta_0}^{(2)} - {\beta_0}^{(1)} + {\epsilon_i}^{d}$, and the effects of any of any time-invariant covariates, including aptitude, are removed from the difference score. In the educational research literature, the analysis of difference scores is more commonly known as the analysis of gains (Cooper et al., 2009). The full model for the analysis of difference scores is given by

$$D_{ijks} = \beta_0 + \alpha_j + \gamma_k + \upsilon_s + \epsilon_{ijks}$$

where $D_{ijks} = Y_{ijks2} - Y_{ijks1}$ is the difference score for student *i* nested in course section *s* in year *k*. α_j is the summer gap effect. It is assumed that $\upsilon_s \sim N(0, {\sigma_\upsilon}^2)$ and $\epsilon_{ijklrs2} \sim N(0, {\sigma_\varepsilon}^2)$, independent of υ_s. The model implies that measurements on students within the same class section of Calculus 2 are correlated but measurements across different sections and across years are independent. The test of the summer gap effect controls for all time-invariant student characteristics and year, ethnicity, and gender effects are not included in the model because ethnicity and gender are time-invariant covariates at the student level. Since the model includes both fixed and random effects, it is a mixed model, as before.

When allocation to treatments (SO vs ST) is not random, the analysis of covariance and the analysis of difference scores have different interpretations, a point made famous in Lord's Paradox (Lord, 1967). The treatment effect in the analysis of covariance is interpreted as conditional on the covariates included in the model. In the analysis of difference scores, the treatment effect is interpreted as unconditional, and the effect of all student-level time-invariant covariates is eliminated.

Results

Success rates

First, we sought evidence for the summer gap effect by comparing the success rates in Calculus 2 of SO and ST students for each of the five academic years. As can be seen in Figure 1, a much higher percentage of SO versus ST students failed to successfully complete Calculus 2 with a grade of C or above. Across academic years, an average of 44.0% SO students received a grade of D or below in Calculus 2 or withdrew, compared with 20.0% of ST students. Thus, students who have a summer gap between the two sequential courses perform much more poorly than do students who take Calculus 2 directly after the completion of Calculus 1.

In case the striking difference in success rates could be attributed to the presence of more weak students in the SO cohorts, we then looked for evidence of the summer gap effect on the strongest students in Calculus 1 (i.e., those who received a course grade of B- or above) by tracking their performance in Calculus 2, depending on their summer off status. In particular, we looked at the percentage of strong Calculus 1 students who dropped at least two grade levels in Calculus 2, for instance going from an A in Calculus 1 to a C or below in Calculus 2 or from a B in Calculus 1 to a D or below in Calculus 2. As shown in Figure 1 (right), even the most successful Calculus 1 students are affected by the summer gap. Across academic years, an average of 25.8% SO versus 11.9% ST students who received a grade of B- or higher in Calculus 1 dropped more than two letter grades in Calculus 2. This means that approximately one quarter of the strongest students in Calculus 1 who took the summer of between the two courses could not sustain their success and performed much more poorly in Calculus 2. Strong students who have a summer gap between the two sequential courses perform much more poorly than do strong students who take Calculus 2 directly after the completion of Calculus 1.

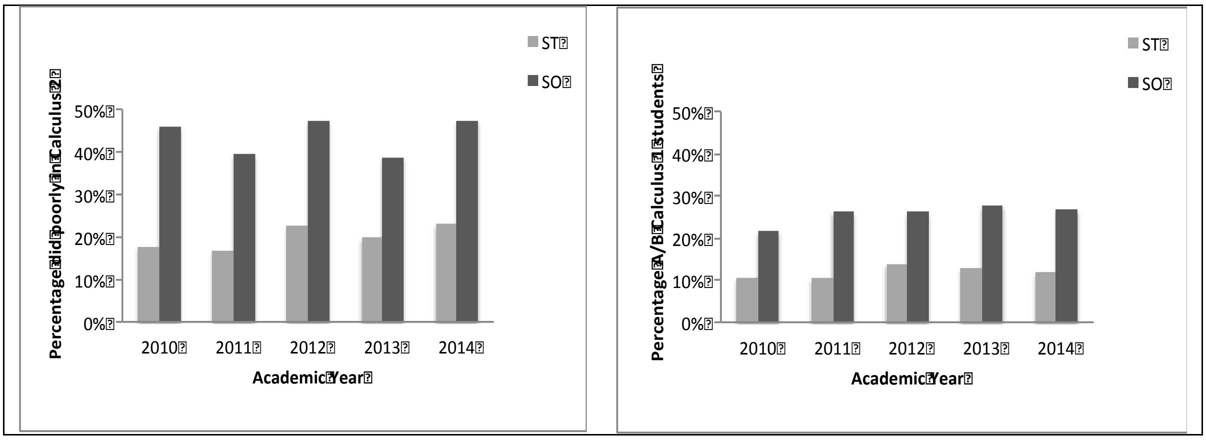

Figure 1. *(left)* Percentage of students who received a grade of D, failed, or withdrew from Calculus 2, by academic year and summer off status. *(right)* Percentage of students who received an A or B in Calculus 1 and dropped at least two letter grades in Calculus 2, by academic year and summer off status.

Covariance

To obtain an estimate and test of the summer gap effect, the mixed model was estimated with SAS PROC MIXED software. Results for the analysis of covariance model are shown in Tables 3-5. Table 3 shows tests of model fixed effects, where it can be seen that the summer-off effect on Calculus 2 course grade is highly significant. Ethnicity is also significant in that students with unreported ethnicities have higher Calculus 2 grades than students within other ethnicity categories. The year and gender effects are not significant.

Table 3. ANCOVA fixed effect results across all years

Effect	Num DF	Den DF	F value	Pr > F
Calculus 1 grade	1	4047	1638.28	< 0.0001 **
Summer off status	1	4047	19.43	0.0001 *
Year	4	160	1.49	0.2065
Ethnicity	4	4047	21.57	< 0.0001 **
Gender	1	4047	1.77	0.1834

Table 4. Maximum likelihood estimates for fixed effects

Effect	Level	Estimate	Standard Error	DF	*t*-value	Pr > |*t*|
Intercept		-0.04729	0.1120	160	-0.42	0.6735
Calculus 1 grade		0.7512	0.01856	4047	40.48	<0.0001**
SO		-0.3675	0.08337	4047	-4.41	<0.0001**
ST		0	-	-	-	-
Year	2010	0.07732	0.1372	160	0.56	0.5737
Year	2011	0.08832	0.1269	160	0.70	0.4874
Year	2012	-0.1575	0.1236	160	-1.27	0.2046
Year	2013	-0.1060	0.1238	160	-0.86	0.3929
Year	2014	0	-	-	-	-
Ethnicity	Asian	0.09453	0.06247	4047	1.51	0.1303
Ethnicity	Hispanic	-0.05377	0.04586	4047	-1.17	0.2410
Ethnicity	Other	-0.1193	0.06275	4047	-1.90	0.0574
Ethnicity	No Report	0.4272	0.05254	4047	8.13	<0.0001**
Ethnicity	White	0	-	-	-	-
Gender	Female	0.05950	0.04472	4047	1.33	0.1834
Gender	Male	0	-	-	-	-

Maximum likelihood estimates of the model fixed effects are shown in Table 4, where it can be seen that the estimate of the SO vs ST effect is -0.3167, controlling for Calculus 1 course grade, year, ethnicity, and gender. The estimate means that ST students are estimated to have a Calculus 2 course grade that is higher than SO students by the amount 0.3675. Least-squares means under the analysis-of-covariance model are shown in Table 5, where it can be seen that the estimated Calculus 2 mean for ST students is 2.49, and the estimated mean for SO students is 2.12, reflecting the estimated effect of -0.3675 or the equivalent of almost half of a letter grade. We also stratified the analysis by examining the summer-gap effect for AB students (Calculus 1 grade $\geq$ 2.67) and C students separately. Results from the stratified analysis were very similar to the results reported here for the pooled analysis.

Table 5. Least squares means for Calculus 2 grade

Effect	Level	Estimate	Standard Error	DF	*t*-value	Pr > |*t*|
Ethnicity	Asian	2.3292	0.07058	4047	33.00	<0.0001**
Ethnicity	Hispanic	2.1809	0.05589	4047	39.02	<0.0001**
Ethnicity	Other	2.1154	0.06978	4047	30.31	<0.0001**
Ethnicity	No Report	2.6619	0.06113	4047	43.54	<0.0001**
Ethnicity	White	2.2347	0.04804	4047	46.51	<0.0001**
ST		2.4881	0.05549	4047	44.84	<0.0001**
SO		2.1206	0.06712	4047	31.59	<0.0001**
Year	2010	2.4013	0.1055	160	22.76	<0.0001**
Year	2011	2.4123	0.09239	160	26.11	<0.0001**
Year	2012	2.1665	0.08729	160	24.82	<0.0001**
Year	2013	2.2179	0.08736	160	25.39	<0.0001**
Year	2014	2.3240	0.09169	160	25.35	<0.0001**
Gender	Female	2.3341	0.05630	4047	41.46	<0.0001**
Gender	Male	2.2746	0.04404	4047	51.65	-<0.0001**

Difference Scores

Although the test of the summer gap effect in the analysis of covariance controls for Calculus 1 course grade, year, ethnicity, and gender, there are many other time-invariant characteristics of students that are not controlled for in this analysis. In particular, the analysis of covariance model did not control for aptitude. Since it could be the case that SO students have lower mathematics aptitude, we turn next to the analysis of difference scores which controls for all time-invariant student characteristics, including aptitude. The difference score model was estimated as a mixed model using SAS PROC MIXED. Results for the difference score model are shown in Tables t-9. As can be seen in Table 6 in the analysis of difference scores, Calculus 1 course grade was a confounder of the relationship between the summer gap effect and the difference score. While the summer-gap effect is marginally significant in the pooled sample, the difference-score analysis stratified by Calculus 1 course grade shows that the summer-gap effect is highly significant for AB students, but not for C students.

Table 6. Estimates of summer gap effect across all years by Calculus 1 course grade

Grade	Factor	n (SO)	n (ST)	Estimate	F	p-value
Pooled grades	Summer gap	1027	3203	-0.422	3.35	0.0674
	Year				1.62	0.1720
B- and higher	Summer gap	429	2102	-0.4336	28.09	<0.0001**
	Year				2.31	0.0605
C+ and lower	Summer gap	598	1101	0.0021	0.0004	0.9853
	Year				1.10	0.357

The summer gap effect of -0.422 from the analysis of difference scores in Table 6 is comparable with the summer gap effect of -0.3675 from the analysis of covariance. From the analysis of difference scores on the stratified sample in Table 6, there is an even larger summer gap effect of -0.4336 for AB students. Table 7 shows difference score results by year.

Table 7. Estimates of summer gap effect by year and Calculus 1 course grade

Grade	Year	n (total)	n (SO)	n (ST)	Estimate	*t*	p-value
B- and higher	2010	369	78	291	-0.3189	-1.35	0.1763
	2011	471	76	395	-0.6830	-3.79	0.0002 *
	2012	609	111	498	-0.3830	-2.85	0.0045 *
	2013	604	104	500	-0.3157	1.65	0.0992
	2014	478	60	418	-0.4384	-2.69	0.0075 *
C+ and lower	2010	256	96	160	-0.4638	-1.52	0.1308
	2011	306	90	216	-0.2166	-0.94	0.3479
	2012	376	123	253	-0.03293	-0.12	0.9010
	2013	362	217	145	0.2829	1.23	0.2202
	2014	388	141	247	0.2244	0.83	0.4070

Table 8 shows estimates of mixed-model variance components and the estimated intra-section correlation. The intra-section correlation ranges from 0 to 1.0 and is a measure of the degree of correlation among measurements taken in the same class section. The correlation among students in the same classroom section would be due to, among other effects, the instructor effect. An intra-section correlation of 0.1 is considered moderate, and an intra-section of 0.2 is considered large. As can be seen in Table 8, the intra-section correlation for C students is substantially larger than the intra-section correlation for AB students, even though the sections for AB and C students are the same. The difference suggests that the instructor effect is larger for C students.

Table 8. Estimates of variance and intra-section correlation for nested error model

Grade	Between section	Error	Intra-section correlation
Pooled grades	0.210	1.234	0.146
B- and higher	0.117	1.040	0.101
C+ and lower	0.350	1.430	0.197

Discussion

Summer learning loss has been well documented in K-12 education. Taking a long period of time off between school years sets students back in many core subject areas, and especially in math (Cooper et al., 1996). Our study extends these results by showing that a lengthy hiatus between university courses can also negatively affect student success. We found much higher failure rates in sequential engineering mathematics courses that were interrupted by a 3-month long summer break compared with those taken within a single academic year.

One explanation for these findings might be that the grades of SO and ST students are not analogous; in other words, grades in off-semester offerings of the courses could be inflated so that SO students receive higher grades than their ST counterparts in each course. Strong SO students would therefore be weaker mathematically than strong ST students at the completion of Calculus 1, and thereby less prepared for Calculus 2. However, fall and spring versions of Calculus 1 and Calculus 2 have comparable exams and use a grading policy based on raw percentages rather than a curve, and our difference score analysis controlled for preparation level. Even if SO students did have lower mathematical aptitude than ST students, the summer gap effect still holds.

Also, in line with the K-12 summer gap research, we did not find an influence of gender on summer learning loss, although we did find an effect of ethnicity. There was no difference in course performance between various ethnicities, but international students who did not report an ethnicity demonstrated higher Calculus 2 grades than other students. There is no theoretical rationale for why this individual difference might be important; instead, it may be due to the fact that the international students represent the very best students from other countries who come to the United States to attend university.

It may seem logical to attribute the summer gap effect to low performing students in the first course who then fall even further behind with no practice over the summer, and therefore fail the sequential course. However, we found the opposite to be true. Students with high course grades who take the summer off between two sequential mathematics courses are more likely to perform poorly in the second course than their counterparts who take the two courses within the same academic year. In contrast, students with average course grades (or below) in the first course did not demonstrate the same slide in their performance in the second course as a result of the summer gap.

One possible explanation for the different effect of the summer gap on strong and weak students is that weaker students are less impacted by the length of the break between the two courses; there is a three-week break between the two sequential courses within an academic year, compared with the three-month summer break that separates academic years. If students have not completely and confidently mastered the material at the completion of the first course, a three-week break is likely to have the same effect as a three-month break on the retention of knowledge that is needed in the sequential course. In other words, because they have a more fragile understanding of the material, it may matter less if weaker students take the two courses within an academic year, or if they take a much more lengthy summer break between the two courses.

Students who have mastered the material in the first course and receive high grades, though, suffer from the lack of practice that accompanies taking the summer off between the two sequential courses. In terms of a practice schedule, these students are essentially given massed practice sessions (during the first course) with no spaced practice over a long retention interval (between the two courses). In other words, their opportunities for practicing the material occur at the time they learn the material and not during the time between the two courses. With respect to learning to solve single kinds of problems, such a practice schedule does not favor long-term retention. Rohrer & Taylor (2006) found that the benefits of spacing on retaining the ability to solve math problems grow with the retention interval; practice sessions that are distributed over time have the most effect on performance after an extended period of time. Our results align with those of Bahrick & Hall (1991) showing that this same phenomenon exists at a larger-grained level involving multiple kinds of problems over long periods of time. A lack of opportunities for spaced practice over the summer months lowers course performance of the strongest students and may therefore hinder many talented students from pursuing an engineering degree at a critical time as they start their university studies.

Despite various responses to calls for improving mathematics and science education by supporting and retaining engineering majors (Pomalaza-Raez & Groff, 2003; Knight, Carlson, & Sullivan, 2007) and especially freshmen (Moller-Wong & Eide, 1997; Veenstra, Dey, & Herrin, 2009), the number of students pursuing degrees in engineering is not keeping pace with the need (U.S. Department of Education, 2013). Although many students enter university with plans for receiving a degree in engineering, they ultimately switch to other areas of study when they fail to succeed in requisite courses (Klobuchar, 2014). Our research suggests that the summer gap may contribute to this problem. Engineering students who take the summer off between sequential core mathematics courses are much more likely to fail than are students who take the course sequence within a single academic year, and the learning loss is particularly harmful for stronger students. The challenge, then, is for universities to follow suit with K-12 education by searching for creative ways to bridge the summer gap and stem the outflow of undergraduate engineering majors.

References

Bahrick, H. & Hall, L. K. (1991). Lifetime maintenance of high school mathematics content. *Journal of Experimental Psychology, General, 120, (1),* 20-33.

Barrett, M. J. (1990). The case for more school days. *Atlantic Monthly, 266*, 78-106.

Cooper, H. (1989). *Homework.* White Plains, NY: Longman.

Cooper, H. (2003). Summer learning loss: The problem and some solutions. Retrieved from http://www.ldonline.org/article/8067/

Cooper, H., Hedges, L. V., & Valentine, J. C. (Eds.) (2009). *The handbook of research synthesis and meta-analysis.* New York: Russell Sage Foundation.

Cooper, H., Nye, B., Charlton, K., Lindsay, J., & Greathouse, S. (1996). The effects of summer vacation on achievement test scores: A narrative and meta-analytic review. *Review of Educational Research, 66*, 227-268.

Ebbinghaus, H. (1964). *Memory: A contribution to experimental psychology*. New York: Dover.

U.S. Department of Education. (2013). *Table containing number and percentage distribution of science, technology, engineering, and mathematics (STEM) degrees/certificate, and sex of student: 2008-09 through 2012-13.* Technical Report National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS). Retrieved from http://nces.ed.gov/programs/digest/

Geary, D. C. (1995). Reflections of evolution and culture in children's cognition. *American Psychologist, 50*, 24-37.

Gold, K. M. (2002). *School's in: The history of summer education in American public schools.* New York: Peter Lang.

Harris, E., & Wallace, A. (2012). *Year-round learning: Continuity in education across settings and time through expanded learning opportunities.* Technical Report Brief No. 3 Harvard Educational Research Project and The National Conference of State Legislatures.

James, H. W. (1930). The semester versus the quarter. *Journal of Higher Education, 1*, 398-400.

Klobuchar, A. (2014). *STEM: Education for the Innovation Economy.* Technical Report Joint Economic Committee, United States Congress.

Knight, D. W., Carlson, L. E., & Sullivan, J. F. (2007). Improving engineering student retention through hands-on, team-based, first-year design projects. In *31st International Conference on Research in Engineering Education (ICREE)* ISBN: 0-87823-193-5. Honolulu, HI.

Lord, F. M. (1967). A paradox in the interpretation of group comparisons. *Psychological Bulletin, 68*, 304-305.

Moller-Wong, C., & Eide, A. (1997). An engineering student retention study. *Journal of Engineering Education, 86*, 7-15.

Murname, R. (1975). *The image of school resources on inner-city school children.* Cambridge, MA: Ballenger.

Pomalaza-Raez, C. & Groff, H. B. (2003). Retention 101: Where robots go…students follow. *Journal of Engineering Education, 92*, 85-90.

Rohrer, D. & Taylor, K. (2006). The effects of overlearning and distributed practice on the retention of mathematics knowledge, *Applied Cognitive Psychology, 20,* 1209-1224.

Rohwedder, S., & Willis, R. J. (2010). Mental retirement. *Journal of Economic Perspectives, 24*, 119-138.

Skinner, R. R. (2014). Year-round schools: In brief. Congressional Research Service Report R43588.

Smith, M. (2012). Strength in numbers. Inside Higher Ed. Retrieved from www.insidehighered.com/news/2012/02/07/colleges-increasingly-switching-quarters-semesters.

Veenstra, C. P., Dey, E. L., & Herrin, G. D. (2009). A model for freshman engineering retention, *Advances in Engineering Education*, January, 1-33.

Author Information

Carla van de Sande
Arizona State University
School of Mathematical & Statistical Sciences
Tempe, Arizona
USA
Contact e-mail: *carla.vandesande@asu.edu*

Mark Reiser
Arizona State University
School of Mathematical & Statistical Sciences
Tempe, Arizona
USA