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People systematically underestimate exponential growth. This article illustrates this phenomenon, its implications, and some potential interventions in the context of saving for retirement, where savings grow exponentially over long periods of time. Experiment 1 shows that a majority of participants expect savings over 40 years to grow linearly rather than exponentially, leading them to grossly underestimate their account balance at retirement. Experiment 2 demonstrates that this misunderstanding leads to underestimates of the cost of waiting to save, which makes putting off saving more attractive than it should be. Finally, Experiments 3–5 show that highlighting the exponential growth of savings motivates both college students and employees to save more for retirement. Making clear to employees the exponential growth of savings before they make crucial decisions about how much to save may be a simple and effective means of increasing retirement savings.

Keywords: retirement savings, behavioral finance, bias, cognitive errors, financial decision making

Misunderstanding Savings Growth: Implications for Retirement Savings Behavior

Significant change has marked retirement plans in the United States in the past 30 years. In 1979, 62% of private-sector workers participated solely in defined benefit (i.e., pension) plans. Under such plans, employers put aside money for employees, who, on retiring, typically receive a monthly paycheck for the rest of their lives. Because retirement pay is usually based on years of employment with the firm and/or preretirement income, little or no financial planning is required on the part of employees. That same year, only 16% of participants were solely in defined contribution plans (i.e., 401(k)-type plans). With these plans, employees must decide (1) whether to participate, (2) how much of their monthly income to save for retirement, and (3) how to invest their savings.

By 2005, these percentages had reversed: Only 10% of participants were in defined benefit plans, and 63% were in defined contribution plans (Employee Benefits Research Institute 2007). This dramatic shift is important, because a majority of private-sector employees are now responsible for saving for their retirement. In theory, defined contribution plans provide adequate income during retirement—but only if employees save enough during their working years.

Unfortunately, there is evidence that people are not saving enough for retirement. Approximately 45% of households were "at risk" in 2004, meaning that they were predicted to fall significantly short of having enough money at retirement to maintain their preretirement standards of living (Munnell, Webb, and Delorme 2006; Munnell, Webb, and Golub-Sass 2007). Indeed, because so many eligible workers were not participating at all in 401(k)-type retirement plans, the Pension Protection Act was passed, in part, in 2006 to make it easier for U.S. companies to enroll employees automatically in plans (Madrian and Shea 2001; McKenzie, Liersch, and Finkelstein 2006). Exacerbating the problem is that the cost of retirement continues to increase as people live longer lives, health care costs

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increase, and Social Security benefits decrease. The combination of increasing retirement costs, the switch to defined contribution plans, and a lack of retirement savings is thus a serious concern.

Various explanations have been offered for why people do not save enough, including weakness of will and excessive intertemporal discounting (e.g., Laibson 1997; Thaler and Benartzi 2004). Such explanations implicitly assume that people have a basic understanding of how savings grow over time. In this article, we show instead that people have a deep and fundamental misunderstanding of savings growth: Due to compound interest, savings grow exponentially over time, but most undergraduate students believe that savings grow linearly, and they therefore grossly underestimate how much money can accumulate over the span of a typical career (as we show in Experiments 1 and 5). Because they believe that savings grow linearly, they also underestimate the cost of waiting to save, which makes the decision to put off saving more appealing than it ought to be (Experiment 2). However, we show that increasing students' (Experiments 3 and 5) and real employees' (Experiment 4) awareness of the exponential growth of savings over time, even subtly, helps them appreciate the benefits of saving and motivates them to save more for retirement.

Calculating savings with compound interest is not simple, and estimating it is not intuitive. Imagine that you deposit $1,000 at the beginning of each of three years and earn 7% interest, compounded annually. After three years, how much money will you have? The $1,000 deposited three years ago has grown to $\$1{,}000(1.07)^3$, or $1,225; the $1,000 deposited two years ago has grown to $\$1{,}000(1.07)^2$, or $1,145; and the $1,000 deposited last year has grown to $1,000(1.07), or $1,070. The total then is $3,440. To calculate the total savings in one fell swoop, we can use the following equation: annual deposit $([(1 + \text{rate})^{\text{years}+1} - 1]/\text{rate}) - \text{annual deposit}$. In our hypothetical case, $\$1{,}000([1.07^4 - 1]/.07) - \$1{,}000 = \$3{,}440$. Note that the total is almost 15% (not 7%) more than the total amount deposited, because each year you earn interest on the previous interest earned. After depositing $1,000 each year for 40 years at 7% annual compound interest, you will have deposited $40,000 but have savings of $213,610, or 434% more than total deposits.

People's poor understanding of exponential growth has been shown in other, nonsavings domains. When presented with initial data in an exponentially increasing series and asked to estimate future values, participants' estimates are much too low. This highly robust phenomenon occurs whether the initial data are presented numerically, graphically, or perceptually (Jones 1979; Wagenaar and Sagaria 1975; Wagenaar and Timmers 1978, 1979).

Stango and Zinman (2009) recently have provided evidence that underestimating exponential change affects real household financial outcomes, such as more borrowing, less saving, and lower net worth. They use data from surveys conducted in the 1970s and 1980s that asked (among many other questions) for an estimate of how much money respondents believed it would cost to repay a $1,000 purchase in 12 monthly installments. Repayment estimates were to include all finance and carrying charges. Respondents were subsequently asked to provide the interest rate that their estimate implied. For example, a respondent might estimate a total repayment of $1,200 and then provide an implied interest rate of 20%. However, given the $1,200 estimate, a 20% interest rate would be too low: Because monthly payments are being made, the principal declines each month, so paying $200 in finance charges implies a higher interest rate—35% in this case. Indeed, 98% of participants reported overly low interest rates. Stango and Zinman consider the difference between the estimated and actual implied interest rate a measure of payment/interest bias, which correlates with several important measures (e.g., negatively correlated with net worth).

As interesting as these findings are, it is not obvious that payment/interest bias results from a failure to appreciate exponential growth. The authors show analytically that payment/interest bias is consistent with underestimating exponential change, but there are other explanations of their measure too. For example, failing to take into account that the principal declines each month when estimating the implied interest rate is psychologically distinct from failing to appreciate exponential change. From our perspective, the strength of Stango and Zinman's (2009) results is their ability to connect payment/interest bias to important, real-world data. The two questions (repayment total and implied interest) that Stango and Zinman use provide a proxy for people's understanding of exponential change, but we are more interested in examining this understanding directly in the context of saving for retirement. We probe people's understanding using a variety of independent and dependent measures, and we conduct experiments with random assignment to test potential interventions.

To our knowledge, only Eisenstein and Hoch (2007) have studied people's understanding of compound interest systematically. They examine understanding of growth for one-time investments rather than, as in retirement savings, recurring deposits. For example, they asked respondents: "If you deposit $1,000 today into an account earning 9% interest compounded annually, how much money would be in the account after 24 years?" The majority of their participants underestimated growth; in particular, many thought that the investment would grow linearly. For one-time investments (compared with retirement savings, for which money is deposited each month), there is a simple heuristic, the Rule of 72, that can estimate future dollars. Dividing 72 by the annual interest rate results in a good approximation of how many years it will take for the investment to double (eight years in the case of 9% annual return). Some participants knew the rule and used it, which reduced error. Eisenstein and Hoch taught the rule to some participants and found that doing so also reduced error.

There is no simple heuristic analogous to the Rule of 72 for retirement savings though. Furthermore, as we report in Experiment 2, participants who demonstrate an understanding of compound interest do not appreciate the exponential growth of savings any more than participants who do not understand compound interest or even know what it is. Therefore, the intervention we describe in this article is aimed not at helping people understand or calculate compound interest but rather at getting people to see the implications of compound interest, namely, the exponential growth of savings. When people consider exponential growth, they are more motivated to save more now. Because our intervention points out to participants that they will have more savings at retirement than they otherwise would have thought, it conceivably could leave them less motivated to save more. We show that the opposite occurs.

Most participants in our experiments are undergraduate students, who might be a questionable population for studying retirement savings. However, we consider this population nearly ideal: Many students will be starting their first full-time jobs within a year or two and making crucial decisions about saving for retirement. Because the benefits of compound interest are best exploited by workers early in their careers, undergraduate students are a perfect group to study. However, to increase the generalizability of our findings, we test our intervention using both undergraduate students (Experiments 3 and 5) and employees at a *Fortune* 100 company (Experiment 4).

EXPERIMENT 1

With our first experiment, we tested undergraduate students' intuitions about retirement savings growth over a span of 40 years. Assuming the typical college-educated worker retires in his or her early to mid-60s, 40 years is approximately the length of a typical career, during which a worker can put aside money each month for retirement. Previous psychological research on exponential growth generally has provided participants with starting values of a series but not any information about the true underlying relationship, then asked them for predictions of future values (Jones 1979; Wagenaar and Sagaria 1975; Wagenaar and Timmers 1978, 1979). In contrast, we provide participants with all the necessary information to calculate savings (monthly deposit amount and annual rate of return) over various lengths of time but not a series of initial values. This approach eliminates any uncertainty about whether the relationship will continue over time, which could cause participants to dampen their future predictions (Eisenstein and Hoch 2007). The approach also enables us to investigate people's understanding of retirement savings at the very beginning of the process, when they would have few or no data points from which to extrapolate. It is just these people who stand to gain the most from exponential growth but often fail to do so.

Method

Participants were 99 undergraduate students at University of California San Diego (UCSD) who received partial credit in psychology courses for their participation. They filled out a survey in a laboratory setting in groups of up to 5 people. The cover page provided the following instructions:

> It is becoming common for employees to save for their own retirement rather than have their employers pay for it. We are interested in college students' thoughts about saving for their retirement. On the following pages, you will be asked some questions about saving for retirement. We realize that you might not know a lot about this topic; we just want you to do the best you can.

Participants were randomly assigned to either the "no aid" condition or the "aid" condition. In the no aid condition, the next paragraph of instructions, still on the cover page, followed:

> When answering the questions, please provide your thoughtful best guess. In other words, it is important that you do not formally calculate your answers (e.g., by using a calculator or using this survey as scratch paper). We want your best guess!

The aid group instead read:

> When answering the questions, please calculate your answers using the calculator and/or using the survey as scratch paper. In other words, it is important that you do not simply provide a best guess (e.g., don't respond with a number that just pops into your head). We want your calculated answer!

Thus, the no aid group was explicitly forbidden from using any sort of external aid, whereas the aid group received explicit instructions to use external aids. The aid group also had access to a basic calculator that helped them add, subtract, multiply, and divide, to minimize simple arithmetic mistakes.

Two pages of questions followed. One page asked how much money would be in a savings account, given that a fixed amount of money was deposited every month ($200 or $400), at a certain annual interest rate (5% or 10%), over different amounts of time (10, 20, 30, or 40 years). These variables were manipulated within participants, resulting in 16 questions. For example, for half of the participants, the first 4 questions were:

> Assume that you deposit $400 every month into a retirement savings account that earns a 10% yearly rate of interest. (You never withdraw any money.) How much money do you think you will have in your account (including interest earned):
>
> After 10 years? $______ After 20 years? $______
> After 30 years? $______ After 40 years? $______

The other page of questions first asked for participants' "Savings Goal": how much they thought they would need to save if they were going to retire in 40 years. They then indicated how much they would need to save each month to reach their savings goal in 40 years at annual return rates of 5% and 10%, as well as the annual return rate they would need to reach their savings goal if they were saving $200 or $400 per month.

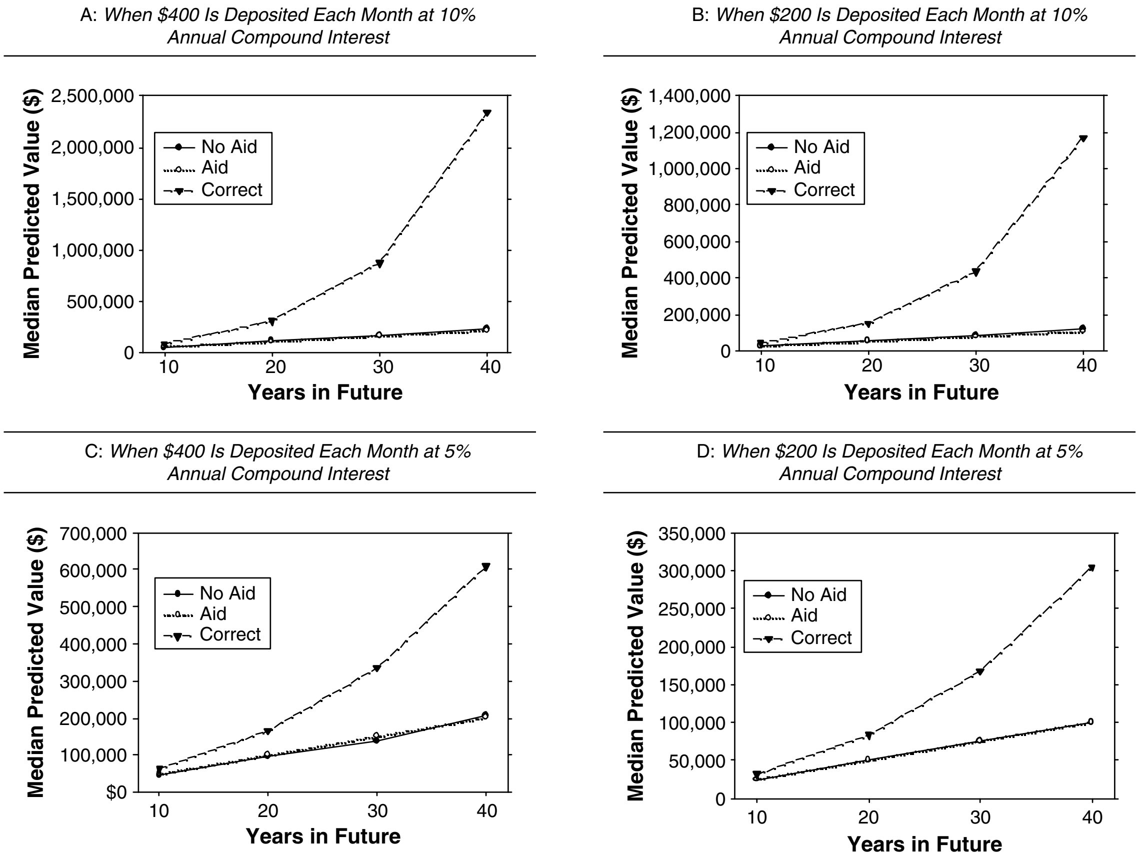
The order of the two pages of savings questions was manipulated. Within each page, the question order also varied, so half the participants saw the questions in one order, and half saw the questions in reverse order (with the exception of the savings goal question, which always came first on the page where it appeared).

The last page of the survey asked participants in the no aid condition whether they made their judgments without using a calculator or pencil and paper. If they answered "yes," they were asked whether they thought they would have given more accurate responses if they had used a calculator or pencil and paper. Those in the aid condition were asked if they used a calculator or pencil and paper and, if so, whether they thought they would have given less accurate responses if they had not used any such aid.

Results

In Figure 1, we depict the median responses, along with the correct responses, for the "how much money after X years?" questions. We report the medians because the distributions are highly positively skewed. Figure 1, Panel A,

Figure 1
EXPERIMENT 1: CORRECT AND ESTIMATED SAVINGS OVER 40 YEARS



Notes: In each case, the aid and no aid condition medians are linear, almost identical, and far from the correct values.

contains the results for deposits of $400/month at 10% annual compound interest for both the no aid and aid groups. The results are essentially identical and very different from the correct responses. The median responses systematically underestimate how much money will be in the account at each point in time, and the underestimation increases with time. Participants' median responses increase linearly over time, whereas the correct responses increase exponentially. Therefore, the errors are quite large after 40 years, with median responses less than 10% of what they should be and an underestimation of $2.2 million.

It is also clear how most participants, especially in the aid condition, calculated their responses. After 10 years, the modal response (by 60% of aid participants) was $52,800, which corresponds to $400 × 12 (months per year) × 10 (years) × 1.1. That is, rather than calculating annual compound interest, participants merely added 10% to their 10-year total and thus arrived at estimates of $105,600 after 20 years, $158,400 after 30 years, and $211,200 after 40 years—both the median and modal responses for the aid group. Across the four time periods, between 60% and 64% of the aid participants reported exactly these values. The results are very similar for the no aid participants. The median (modal) response was $50,000 ($50,000) after 10 years, $109,000 ($100,000) after 20 years, $160,000 ($150,000) after 30 years, and $223,000 ($200,000) after 40 years. Across the four time periods, between 10% and 20% of no aid participants provided the modal response.

Panels B–D in Figure 1 indicate the results for the other combinations of annual rate of return and monthly deposit. The patterns are essentially identical for all four cases. No fewer than 84% of participants underestimated the correct value in either condition for any of the 16 questions (all *ps* $< .001$, two-tailed binomial test; null hypothesis $p = .5$). Across conditions and questions, a mean of 90% of participants underestimated the correct value.

The other page of questions asked participants how much money they thought they would need to save for retirement ("Savings Goal"). The median response was $500,000 for both groups, and the interquartile range was approximately $250,000–$950,000 in each case. Participants were asked how much they would need to save each month to reach their savings goal with annual returns of 5% and 10%. If they did not consider exponential growth, they should have responded with monthly deposits that were too high, especially for the 10% question. For each participant, we calculated whether monthly deposits at the specified annual interest exceeded their savings goal. The percentages of aid and no aid participants who reported monthly deposits too high for the 5% return question were 88% and 80%, respectively (both *ps* < .001; two-tailed binomial test). The respective percentages for the 10% return question were 98% and 96% (*ps* < .001).

Participants also indicated what annual interest rate they would need to reach their retirement savings goal if they deposited $200 or $400 per month. If participants failed to appreciate exponential growth, they should have reported overly high interest rates. Accordingly, the percentages of aid and no aid participants who reported interest rates that were too high for the $200/month question were 64% (*p* = .065) and 82% (*p* < .001), respectively, and for the $400/month question, these values were 82% for both groups (*ps* < .001).

Finally, despite the virtually identical results for the two groups across all measures, 100% of the aid participants thought they would have given less accurate responses had they not used a calculator, and 88% of the no aid participants thought they would have given more accurate responses had they used a calculator. Participants apparently have little insight into their (in)ability to calculate compound interest accurately or the tools that would aid them in doing so.

Discussion

Participants grossly underestimated retirement savings growth: On average, 90% of them underestimated future savings for 16 questions covering different time horizons, rates of return, and monthly deposit amounts. Furthermore, extending Eisenstein and Hoch's (2007) finding for one-time investments, we found that many participants thought that retirement savings would grow linearly, rather than exponentially. The underestimation of retirement savings growth was evident not only when participants estimated future values but also when they estimated how much they would need to deposit each month, and what annual rate of return they would need, to reach their retirement goal in 40 years.

Eisenstein and Hoch (2007) show that estimates are often based on simple interest, which takes into account the interest rate each year but ignores compounding. Our participants did something even simpler: They applied the interest rate once to the total amount deposited, ignoring that dollars invested for more years accrue more interest. This miscalculation leads to even larger errors relative to calculating simple interest. It could be that the added complexity of the retirement savings scenario (with recurring deposits) in our study prompted simpler response strategies than did the one-time investments used by Eisenstein and Hoch.

EXPERIMENT 2

The finding that participants underestimate retirement savings growth suggests that they do not appreciate the benefits of saving early or, equivalently, the costs of waiting to save. People might put off saving for retirement because they mistakenly assume they can easily make up for lost time later. Saving early in a career is relatively difficult, because people earn relatively low starting salaries, so they may prefer to wait and save more later, when it is easier to do so. Our results thus far indicate that such reasoning is likely to be more appealing than it should be. In Experiment 2, we probe participants' understanding of the cost of waiting to save.

Participants were also asked if they knew what compound interest is and, if so, to provide a brief explanation. Thus, we can determine whether those who understand compound interest perform better than those who do not.

Method

Participants were 100 UCSD students who received partial course credit for their participation. The cover page of the four-page survey provided general instructions and informed participants that they could use calculators if they wished. The calculators were slightly more sophisticated than those in Experiment 1, in that they allowed the use of exponents. Participants then answered two questions, each on a separate page. One question read:

> Imagine that both Alan and Bill just started working and are going to retire in 40 years. Alan deposits $100 every month into his retirement account. Bill waits 20 years to start saving, but then deposits $300 every month into his retirement account. Both accounts earn 10% interest every year, compounded annually. Neither of them withdraws any money. Who has more money at retirement?

Participants circled a number on a seven-point scale, with 1 = "Alan has much more money at retirement," 4 = "equal money," and 7 = "Bill has much more money at retirement." The second question asked:

> Consider again Alan and Bill, who just started working and are going to retire in 40 years. Alan deposits $100 every month into his retirement account. Bill waits 20 years before depositing money into his account. Both accounts earn 10% interest every year, compounded annually. Neither of them withdraws any money. How much money would Bill need to deposit into his account each month in order to have the same amount of money as Alan when they both retire?
>
> Bill would need to deposit $_____ per month.

Half the participants were assigned to a 10% annual rate of return condition and the other half to a 5% annual rate of return condition. Half the participants answered the rating question first, and half answered the deposit question first. The final page asked participants whether they knew what compound interest was and, if so, to provide a brief explanation.

Results

For the rating question, the correct answer is that Alan will have more money. In the case of a 5% annual return, Alan will save $152,208 by depositing $100/month over 40 years, and Bill will save $124,989 by depositing $300/month over 20 years. In the case of a 10% annual return, Alan will save $584,222 and Bill will save $226,809, less than half as much. Only a minority of participants believed that Alan would have more money in either case. In the 5% condition, 36% of participants provided a rating less than 4 (with 4 = "equal money" on the seven-point scale), indicating a belief that Alan would have more money than Bill. The mean, median, and modal responses were 4.5, 5, and 6, respectively. In the 10% condition, even fewer (30%) believed Alan would have more money. The mean, median, and modal responses were 5.0, 6, and 7, respectively.

We conducted a 2 (rate) × 2 (task order) between-participants analysis of variance (ANOVA) on the ratings. We subtracted 4 from each rating so that 0 indicated "equal money," negative values indicated that Alan had more money, and positive values indicated that Bill had more money. The only significant result was that the overall mean (.8) was greater than 0 ($F(1, 96) = 13.8$, $p < .001$), which indicates a tendency to believe incorrectly that Bill would have more money.

We asked participants, "Do you know what compound interest is?" (yes or no), and 53% responded yes. Those who responded yes were asked to write a brief explanation of compound interest. Two independent raters judged whether each response was correct (i.e., interest was earned on previously earned interest), and any disagreements were resolved through discussion. Sixteen of the 53 responses were judged incorrect. Thus, we identified 32 low-knowledge participants and 18 high-knowledge participants in the 5% condition; these respective numbers were 29 and 19 in the 10% condition. (Two participants in the 10% condition did not answer the compound interest question and were excluded from the analysis.) We conducted a 2 (rate) × 2 (task order) × 2 (knowledge) ANOVA on the ratings after subtracting 4 from each rating. Although high-knowledge participants had lower (i.e., better) ratings than low-knowledge participants (.5 vs. .9), the difference was not significant ($F(1, 90) = 1.2$, $p = .28$), and the ratings were positive for both groups. The only significant effect was that the overall mean was greater than 0 ($F(1, 90) = 9.8$, $p = .002$), as we found previously.

The participants also indicated how much Bill, who would be saving for only 20 years, would have to save each month to have as much as Alan, who was saving $100/month for 40 years. In the 5% condition, the correct answer is that Bill needs to save $365/month, but participants' median and modal responses were $200/month; 45% of participants offered this response. In the 10% condition, the correct answer is $773/month, but the median and modal responses were again $200/month; 52% of these participants responded with this dollar value. Because Bill would save half as long, there was a strong tendency among participants to believe that he would need to save twice as much. The results for low- and high-knowledge participants were virtually identical.

Discussion

These results replicate the findings from Experiment 1: Participants viewed retirement savings growth as linear. They also extend our previous results by showing that this linear understanding led participants to underweight the cost of waiting to save. They believed that it would be much easier than it really is to make up for lost time, so the decision to put off saving appeared more attractive than it should be. If participants were correct in believing that Bill could wait 20 years, deposit only twice as much as Alan each month, and have as much as Alan at retirement, putting off saving would presumably make financial sense. People typically earn relatively little early in their careers, so saving is especially difficult. But this line of thinking ignores the annual returns from the initial decades of saving. The higher the rate of return, the more difficult it is for Bill to make up for lost time; however, participants were virtually insensitive to this variable (5% vs. 10% interest rate). Our findings indicate more than just a lack of understanding of compound interest though, because even those who demonstrated an understanding of compound interest performed essentially identically to those who did not understand it or did not know what it was.

EXPERIMENT 3

Experiments 1 and 2 showed that participants vastly underestimated retirement savings growth and the cost of waiting to save. In light of these results, what can be done to increase retirement saving? Experiment 2 indicated it is not enough to understand what compound interest is. We suspected that a more effective way to motivate saving would be to highlight the effect of compound interest, namely, exponential growth. In Experiment 3, we employed an intervention aimed at sensitizing participants to the exponential growth of retirement savings to determine whether it would increase their understanding of the cost of waiting to save and their motivation to save more for retirement.

Highlighting exponential growth conceivably could decrease motivation to save, because participants would realize that they will have more retirement savings than they otherwise expected. That is, for a given savings goal at retirement, participants can learn that they can save less per month than they thought and still achieve their goal. However, seeing the effects of exponential growth should highlight the benefits of saving early and the costs of waiting to save, and these factors might be more important influences on savings behavior.

Method

Participants were 276 UCSD students who received partial course credit for filling out a survey in a laboratory setting. They were randomly assigned to a time, deposit, or control condition. After reading a page of general instructions, all participants read the following instructions: "Imagine that you have just graduated from UCSD and have begun your first full-time job. How motivated would you be during your first year of work to start saving every month for your retirement?" They responded by circling a number on a seven-point scale, with 1 = "not at all motivated" and 7 = "very motivated." They then answered the following item: "How much do you think you would save for retirement each month during your first year of full-time work? $______ per month."

Participants in the time condition then turned to a third page (see Appendix A). They viewed a graph that tracked savings over 40 years with a 10% annual return. One curve depicted savings from monthly deposits of $100, and a second curve depicted savings from monthly deposits of $200. Participants were instructed to refer to the graph when answering several questions printed on the same page. These questions were designed to focus attention on the exponential growth of savings over time. In particular, two questions targeted the notion that saving for 40 years would lead to much more than twice as much money as would saving for 20 years. Question 3 then probed whether participants understood from the graph that saving \$100/month for 40 years would lead to much more money than saving \$200/month for 20 years.

The deposit condition differed only in that the questions focused on the information that saving \$200/month always led to twice as much money as saving \$100/month (see Appendix B). In other words, the questions did not highlight exponential growth, though the graph was identical to the one in the time condition. We simply focused participants' attention on different aspects of the graph. We tried to make Question 3 (basic comprehension of the graph) as similar as possible to that in the time condition, without calling attention to exponential growth. In the control condition, participants did not see this page.

Next, participants returned their survey to the experimenter (i.e., time and deposit participants could not consult the graph while answering subsequent questions). Participants in all conditions then received an identical survey with the two Alan-and-Bill questions from Experiment 2. Finally, they again answered the two questions posed at the start of the experiment: how motivated they were to save for retirement during their first year of full-time employment (seven-point scale) and how much they would save each month for retirement. They were told that they did not have to answer the same way they had answered previously.

Results

The question about who would have more money at retirement featured Alan, who was saving \$100/month for 40 years, and Bill, who was saving \$300/month for 20 years. Both earned 10% interest every year. The correct answer is Alan, who would have more than twice as much money as Bill. Participants answered on a seven-point scale, where 1 = "Alan has much more money at retirement," 4 = "equal money," and 7 = "Bill has much more money at retirement." The mean ratings were 3.9, 4.2, and 4.4 for the time, deposit, and control conditions, respectively. Although the time group performed better, a one-way ANOVA of the ratings revealed no effect of condition ($p = .29$). When we categorized responses as either correct (rating less than 4) or incorrect (rating 4 or greater), a log-linear analysis revealed a significant effect of condition ($\chi^2(2,\ N = 275) = 6.2,\ p = .046$). The percentages of correct responses were 52%, 42%, and 34% for the time, deposit, and control conditions (Figure 2, Panel A). Contrasts revealed that the percentage correct differed only between the time and control conditions ($\chi^2(2, N = 183) = 6.1,\ p = .013$).

Participants also estimated how much Bill would have to save every month to have as much money as Alan at retirement (the correct answer is \$773). The responses were highly positively skewed, so we report only the medians. For the time, deposit, and control conditions, the medians were \$325, \$275, and \$250, respectively (Figure 2, Panel B). Although there was no significant effect of condition on the median values (Kruskall-Wallis one-way ANOVA), the pattern of responses was qualitatively consistent with what we obtained from the "who has more money?" question: Time participants outperformed deposit participants, who outperformed control participants.

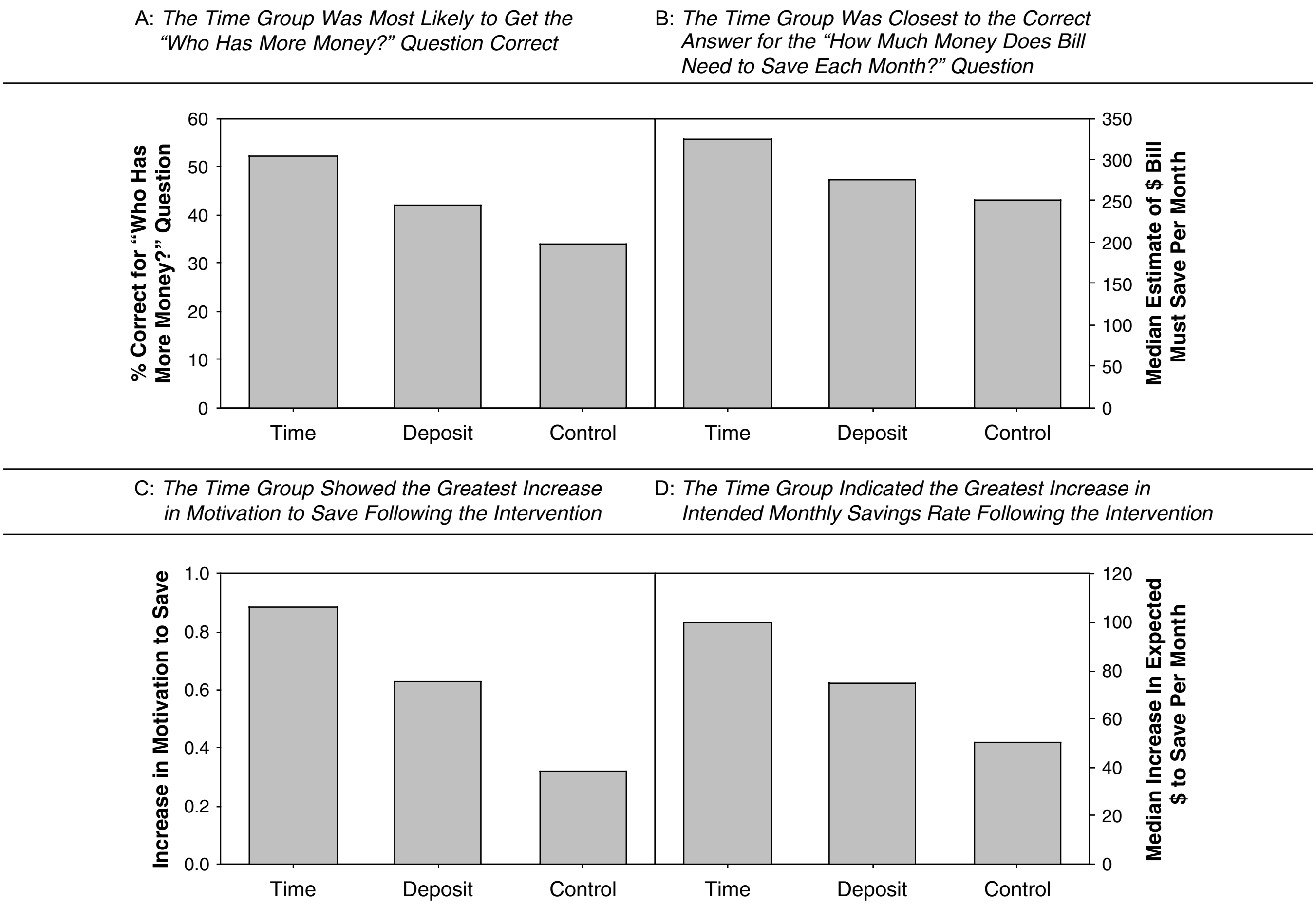
The results for questions asking how motivated the participants were to start saving for retirement during their first year of full-time employment appear in Figure 2, Panel C, for which values represent the increase in motivation (i.e., second reported motivation minus the first). The time participants indicated the largest increase, followed by the deposit and control groups. A 3 (condition: time, deposit, control) × 2 (period: first, second) mixed-model ANOVA on motivation, using period as a within-subject variable, showed a main effect of period; participants reported higher motivation the second time ($F(1,\ 271) = 84.5,\ p < .001$). (Two participants in the time condition did not answer the second motivation question and were excluded from this analysis.) There was also an interaction ($F(2, 271) = 6.0,\ p = .003$), indicating that change in motivation differed across groups. Separate 2 × 2 mixed-model ANOVAs for motivation, essentially serving as contrasts, revealed no significant interaction between condition and period for the time and deposit conditions ($p = .13$), a significant interaction for the time and control conditions ($p < .001$), and a marginally significant interaction for the deposit and control conditions ($p = .051$). Motivation to save increased significantly more for time condition participants and marginally more for deposit participants relative to control participants.

Before and after the experiment, we asked participants how much money they thought they would save per month during their first year of full-time work. The distributions were highly positively skewed, so we report the medians. At the beginning of the experiment, median estimates for all three conditions were \$100/month. At the end, median responses were \$200, \$175, and \$150 per month for the time, deposit, and control conditions, respectively. The increases appear in Figure 2, Panel D. Although these medians were consistent with the results for motivation, we found no significant effect of condition on the median difference between the dollar estimates before and after the experiment (Kruskall-Wallis one-way ANOVA).

Discussion

Although not always statistically reliable, the results across the four dependent measures were highly consistent. Participants in the time group, who answered questions that highlighted the implications of exponential growth, demonstrated the greatest understanding of the cost of waiting to save: They were most likely to answer the question about whether Alan or Bill would have more money at retirement correctly, and they reported answers closest to the correct value when asked how much Bill needed to save each month to have as much money as Alan at retirement. This group was also the most motivated to save more for retirement: They showed the greatest increase in motivation to save for retirement and in the amount they intended to save each month. The results were consistent, in that the control group had the least understanding of the cost of waiting to save and the smallest motivation to save more; the deposit group fell in the middle (Figure 2, Panels A–D). We failed to find reliable differences for the two measures (Figure 2, Panels B and D), with skewed distributions that required nonparametric tests of the medians. The overall pattern is clear however and consistent across measures.

Figure 2
EXPERIMENT 3 RESULTS



Our time intervention mentioned nothing about what compound interest was or how to calculate it. We simply highlighted the implications of the resulting exponential growth. Furthermore, highlighting exponential growth led to more, not less, motivation to save. Realizing that they would have more money than expected at retirement could conceivably make the participants less interested in saving more. However, the more important effect is that participants realize that the benefits of saving early are surprisingly large and that it would be very difficult to make up for lost time later.

EXPERIMENT 4

Although undergraduate students—who will soon be making crucial, early decisions about saving for retirement—form a natural population for these studies, we also wanted to determine whether an intervention similar to that used in Experiment 3 would work among real employees looking at their own 401(k) information. In Experiment 3, the participants in the time and deposit conditions viewed the same graph but responded to different questions, which highlighted different aspects of the graph. This subtle manipulation indicated if the effect of growth rate information increased when people's attention was directed to its exponential properties. A real-life intervention need not be so subtle. The results from Experiment 3 suggest that showing employees how much money they will have at retirement, if they continue saving at their current rate, can motivate them to save even more.

Method

Twenty-two percent of employees at a *Fortune* 100 company received invitations to participate in an experiment via e-mail and were told that, if they participated, they would enter a lottery to win an iPod Nano. Nine percent of those invited chose to participate in the survey, a link to which appeared in the e-mail invitation. Of the participating employees, 250 were randomly assigned to two conditions for this experiment: current account balance group (n = 123) or future account balance group (n = 127). (Other experimental conditions examined the effectiveness of alternative displays, such as estimated income replacement ratios, which are not of interest for this study.) The participating employees were 47% women, with an average age and tenure of 37 years and 8 years, respectively, who earned a mean salary of $38,323. On average, 3% of their total salaries were deferred to their 401(k) account annually, with a current 401(k) account balance of $31,354. There were no significant differences between the groups for any of the demographic variables.

Participants first responded to the item, “Are you interested in changing the amount you save for retirement?” on a seven-point scale, where 1 indicated an interest in saving much less, 4 an interest in saving the same amount, and 7 an interest in saving much more. Participants in the current account balance group then reviewed their actual, current 401(k) balance, supplied to us by their employer. Participants in the future account balance condition saw their estimated account balance at retirement, in today’s dollars, with the assumption of continued annual contributions at their (and their employer’s) current rates, a retirement age of 65 years, an annual return of 8%, and an annual inflation rate of 3%. These assumptions were made explicit (see Appendix C). The median participant in the current account balance condition saw a current balance of $13,886, whereas the median participant in the future account balance condition saw a future balance of $265,100. Participants then answered again the question about whether they were interested in changing the amount they saved for retirement.

Results

A mixed-model ANOVA for interest in changing the saving amount, with account balance (current, future) as a between-subjects variable and period (preintervention, postintervention) as a within-subject variable, showed a significant main effect of period. After seeing either account balance, employees’ interest in saving more increased ($F(1, 248) = 42.2$, $p < .001$, $M = 5.2$ vs. 5.6). There was no significant account balance × period interaction ($p = .16$), though the increase in interest was greater among the future account balance group than among the current account balance group ($M = .50$ vs. .33). We were concerned that the generally high interest in changing savings amounts before the intervention might be limiting our ability to detect differences in the magnitude of change, so we also examined whether the intervention influenced how many participants reported an increase, regardless of the magnitude. Whereas 41% of the participants in the future account balance group reported an increased interest in saving more, only 27% of those in the current account balance group did so ($\chi^2(1, N = 250) = 5.5$, $p = .02$).

Discussion

Employees who saw the estimated account balance of their 401(k) account at retirement were more likely to report increased interest in saving more, compared with those who merely viewed their current account balances. These results conceptually replicate those from Experiment 3 and indicate that because people underestimate their retirement savings growth, showing them how savings grow motivates them to save more. This finding may have an important practical consequence: If employees view estimated future account balances when making decisions about retirement savings, they may choose to save more.

Moreover, more than two-thirds of employees were interested in saving more for retirement, even before they received any savings information. This finding underscores the importance of introducing effective methods for nudging employees into savings decisions that they apparently already want to make (Thaler and Sunstein 2008). In addition, just showing employees their current 401(k) account balances increased approximately one-quarter of the employees’ interest in saving more, suggesting that not only do employees want to save more, but they also recognize that they are not currently saving enough. Combining these results with the finding that showing employees the implications of compound interest makes them want to save more, not less, indicates that employees believe they are saving too little for retirement.

EXPERIMENT 5

There were many variables we could not control or measure in Experiment 4. It is possible that employees in the future account balance condition were surprised not by how large their future account balance would be but rather by how small it would be, which could have motivated them to save more. The results of Experiments 1 and 2 cast doubt on this interpretation, because people tend to grossly underestimate savings growth. Nonetheless, it is useful to confirm whether, when they demonstrably exceed expectations, future account balances motivate saving. Such confirmation would not only overcome a limitation of Experiment 4 but also address more directly an issue we raised previously: Might people be motivated to save less when they see that they will retire with more savings than they had otherwise thought?

Method

Eighty UCSD undergraduate students participated and received partial course credit. They first answered the following prompt:

> Imagine that you have just started your first full-time job and expect to retire in 40 years. You deposit $200 every month ($2,400 every year) into an account that earns 10% interest, compounded annually. You never withdraw any money. After 40 years, you will have deposited $96,000 (40 years × $2,400), but your account earns 10% interest each year. About how much money do you think you will have in your account after 40 years, including interest earned?
>
> I estimate I will have about $______ in my account after 40 years.

All participants turned in this survey and received a new survey on which the experimenter had filled in the blank with the participant’s estimate, in case the participant wanted to refer to it: “If you deposit $200 every month and earn 10% annual compound interest, you estimated that you would have about $______ in your account after 40 years.”

Participants randomly assigned to the compound interest condition (n = 40) read, “In fact, you would have about $1,168,000 in your account.” They then reported how motivated they would be to change the amount they save each month, with 1 = “very motivated to save less,” 5 = “unmotivated to change,” and 9 = “very motivated to save more.” They also indicated how much they would like to deposit each month: $0, $50, $100, $200, $300, $400, or more than $400 each month. Participants in the no compound interest condition received the same surveys, but there was no sentence stating the correct amount they would have in their account after 40 years.

Results

Median estimates of the future account balances from the compound interest and no compound interest groups were \$105,800 and \$106,368, respectively; those in the former group thus should have found the correct amount (\$1.168 million) surprisingly large. (Only 2 participants estimated a value larger than the correct value.) Participants in the compound interest group also reported being more motivated to increase saving than those in the no compound interest group ($M = 8.0$ vs. 7.3; $t(78) = 2.49$, $p = .015$).

We performed an analysis of how much participants wanted to save per month using a scale from 1 (\$0) to 7 (more than \$400), with 4 representing \$200 (current savings amount). There was no difference between groups in terms of how much per month they would save ($t < 1$). Both means were 5.6, corresponding to \$300–\$400 per month. Thus, both groups reported that they wanted to save more each month.

Discussion

Learning what their account balance would be after 40 years of saving motivated participants to save more compared with those who did not see their future account balance. We know that those who saw their future account balance were surprised by how large it was, because these participants first provided estimates, and the median estimate was less than 10% of the correct value.

This scenario has provided a strong test of the effectiveness of our intervention: The correct value of \$1.168 million is considerably more than our participants believed they needed for retirement. In Experiment 1, we asked participants for their savings goal, or how much they thought they would need for retirement. The median response was \$500,000, and 86% of participants reported values less than \$1.168 million. The finding from Experiment 5 thus indicates that seeing the effect of compound interest motivates people to save more, even if the future account balance exceeds their likely savings goal. There are undoubtedly boundary conditions though.

We did not find a similar effect on how much participants were willing to save each month. Both groups reported similar increases in monthly deposits. It may be difficult for participants to map the motivation scale onto a dollar scale in this hypothetical scenario, with no information about their income, for example. Furthermore, the two groups might want to save more but for different reasons. The compound interest group presumably would want to save more because these participants realized the surprisingly large future benefits of saving more now, but the participants in the no compound interest group might want to save more because their estimates of their future account balance left them worried about not having enough money for retirement. In any event, showing people the effect of compound interest on their future account balances is motivating.

GENERAL DISCUSSION

Experiment 1 demonstrated that college students have a fundamental misunderstanding of savings growth. They believed that it grows linearly rather than exponentially, which led to gross underestimates of future value over long periods of time. When given a simple calculator to use and asked to generate the total dollars that would accumulate with monthly deposits of \$400 over 40 years at 10% interest compounded annually, participants' median estimate was less than 10% of the correct value and off by more than \$2 million.

This linear underestimation hindered people from appreciating the cost of waiting to save (Experiment 2). They believed that it would be much easier to make up for lost time than it really is. For example, in one of our scenarios, Alan saved \$100/month for a 40-year period at a 10% interest rate (compounded annually), and participants estimated how much Bill, who waited 20 years to start saving, would need to deposit each month to have as much money as Alan at retirement. More than half of participants judged that it would require twice Alan's savings rate, or \$200/month, for Bill to catch up to Alan. However, Bill would actually have to save nearly eight times as much, or \$773/month. Furthermore, participants' responses were virtually identical regardless of whether they demonstrated an understanding of compound interest. These students will soon be making important decisions regarding when to begin saving for retirement, and how much to save.

It might not be surprising that college students' estimates of savings growth were inaccurate. The calculations are complicated, and there are no simple heuristics for estimating future value. However, it is both interesting and important that this relatively well-educated group underestimated savings growth—and that using a calculator or demonstrating an understanding of compound interest did not help. Their understanding of savings growth was fundamentally mistaken. This misunderstanding is contrary to traditional economic views, which assume that people are capable of calculating future values and making trade-offs with present values. Our findings add to literature that shows that people tend to linearize exponential functions across domains, ranging from the effects of inflation on prices to the growth of duckweed (Eisenstein and Hoch 2007; Kemp 1984; Larrick and Soll 2008; Stango and Zinman 2009; Wagenaar and Timmers 1979). In our studies, the implications of the phenomenon are clear: Failure to recognize the power of compound interest—especially over long periods of time—leads to gross underestimations of future account balances and, thus, underestimations of the costs of waiting to save. The unfortunate effect is a negative impact on people's motivation to save now. Because the benefit of compound interest comes from saving over long periods of time, this lack of motivation is particularly threatening to young people's attainment of their retirement savings goals.

To address this issue, in Experiment 3 we showed participants a graphical intervention that highlighted the exponential growth of savings over time. This tactic increased (1) awareness of the cost of waiting to save, (2) willingness to start saving early, and (3) anticipated monthly deposits. Our findings thus are consistent with other research showing that graphs can improve decision making by encouraging people to incorporate duration into their judgments (Liersch and McKenzie 2009). According to their median responses, students were willing to save \$50 more per month after the intervention (compared with no intervention). An extra $50 per month over 40 years that earned 10% interest annually would amount to over $292,000 in additional savings.

Experiment 4 also showed, with real employees, that highlighting the exponential growth of savings increased motivation to save. Employees at a *Fortune* 100 company who viewed their estimated future 401(k) account balance at retirement were more likely to express an increased interest in saving more (relative to employees who viewed their current 401(k) account balance). It is notable that these real workers' reactions to being presented with exponential growth were similar to those of our undergraduate population, because employees could have developed a more sophisticated understanding of savings growth through their own retirement planning, resulting in immunity to our intervention. Even if these employees remained unsophisticated (i.e., assumed that savings would grow linearly), they may have felt that they were saving enough, and seeing their (surprisingly large) future account balance could have demotivated them. Clearly though, employees were motivated by estimates of their future account balances, presumably because the information highlighted the benefit of saving now. While some researchers have argued that U.S. households are saving enough to reach their optimal wealth targets (Scholz, Seshadri, and Khitatrakun 2006; cf. Munnell, Webb, and Delorme 2006; Munnell, Webb, and Golub-Sass 2007), if the goal is for people to save according to their own preferences, then our intervention may help. Experiment 5 demonstrated in a more direct fashion that showing people the surprisingly steep growth of savings motivates them to save more, not less.

We are not claiming that our interventions increased knowledge of compound interest per se. In Experiment 2, we found that understanding compound interest had no effect on behavior. Instead, our interventions in Experiments 3–5 aimed to highlight the effect of compound interest on saving, and any influence might be transient. Because people often do not follow through, even when they report an interest in increasing their savings rate (Choi et al. 2006), we believe that it is important to introduce exponential growth interventions immediately before savings decisions. For example, the Quick Enrollment program allows employees to make decisions about whether to enroll in 401(k) plans without having to make a savings rate or asset allocation decision (both are predetermined and can be altered at a later date). Including our graphical or projected account balance interventions immediately before the decision to enroll could substantially increase participation rates, beyond what the program already has demonstrated (Choi, Laibson, and Madrian 2006). More generally, presenting interventions before a decision to set or increase savings rates or before a decision to enroll in an automatic increase program (whereby employees elect to increase savings rates automatically over time) may increase employees' savings rates. For example, a human resources department could provide materials to new or eligible employees with simple calculations that illustrate possible future account balances if they were to make particular savings decisions. This information could increase participation and savings rates in a cost-effective manner. Providing people with information, in combination with carefully designed decision architectures, may help employees make better savings decisions (Larrick 2004; Thaler and Sunstein 2008).

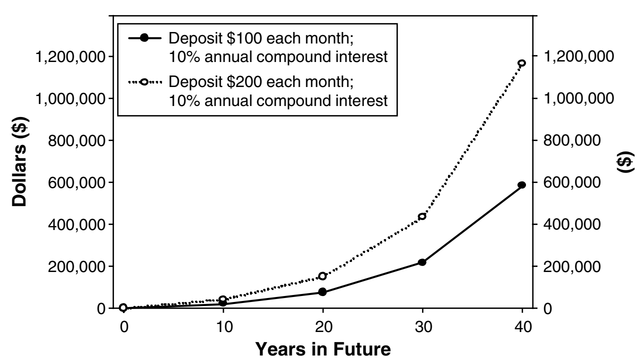
Although extensive financial education may lead people to save more (Bernheim, Garrett, and Maki 2001; Lusardi and Mitchell 2007), Experiment 2 showed that understanding compound interest had no effect on behavior. The results of Experiments 3–5 indicated that people should not simply be taught what compound interest is and how to calculate it. Rather, its effect on savings growth should be illustrated directly, especially over the 40 or so years that people can save for retirement.

Even with extensive education, calculating future account balances is difficult. Assuming U.S. workers know how to calculate future values, access to information about appropriate interest rates and risk–reward trade-offs still may be limited. And calculating future account balances in today's dollars adds an additional layer of complexity, because such calculations require additional formulas and an additional set of assumptions. For example, understanding the impact of low or high inflation on the buying power of a future account balance requires both forward-looking predictions and historical knowledge of how economic and policy shifts have influenced the purchasing power of the dollar for a particular bundle of goods (e.g., real estate vs. commodities).

Perhaps the most important implication of our graphical and projected account balance interventions is that they highlight the cost of waiting to save, and the benefit of saving now, without requiring employees to engage in complex calculations or make decisions about appropriate assumptions (Goldstein, Johnson, and Sharpe 2008). If their demonstrated effects on savings motivation translate into real savings decisions, the simple interventions explored here could contribute substantially to the welfare of retiring workers.

APPENDIX A

The graph below shows amount of money saved over time. Amount of money is on the vertical axis, and time (up to 40 years) is on the horizontal axis. The bottom line (dark circles) in the graph corresponds to depositing $100 each month. The top line (open circles) in the graph corresponds to depositing $200 each month. In both cases, the interest rate is 10%, compounded annually. *Please refer to this graph when answering the questions below* (and please write legibly!).



1a. If you deposited *$100 each month*, about how much money would you have *after 20 years*?

$ ______

1b. If you deposited *$100 each month*, about how much money would you have *after 40 years*?

$ ______

1c. If you deposited *$100 each month*, about how much more money would you have after 40 years compared to after 20 years?

I would have about ______ times more money.

2a. If you deposited *$200 each month*, about how much money would you have *after 20 years*?

$ ______

2b. If you deposited *$200 each month*, about how much money would you have *after 40 years*?

$ ______

2c. If you deposited *$200 each month*, about how much more money would you have after 40 years compared to after 20 years?

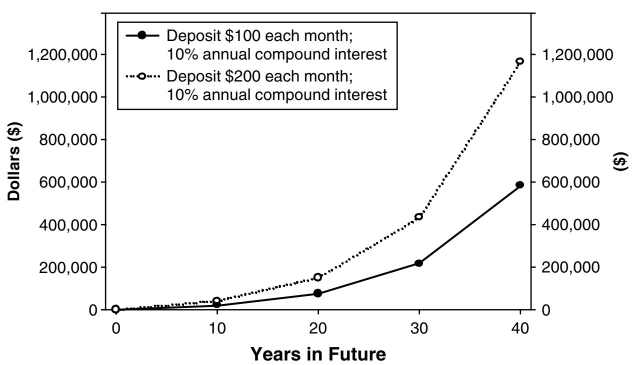
I would have about ______ times more money.

3. Which would lead you to have more money? (check one):

______ Depositing $200 each month for 20 years.
______ Depositing $100 each month for 40 years.

APPENDIX B

The graph below shows amount of money saved over time. Amount of money is on the vertical axis, and time (up to 40 years) is on the horizontal axis. The bottom line (dark circles) in the graph corresponds to depositing $100 each month. The top line (open circles) in the graph corresponds to depositing $200 each month. In both cases, the interest rate is 10%, compounded annually. *Please refer to this graph when answering the questions below* (and please write legibly!).



1a. If you deposited *$100 each month*, about how much money would you have *after 20 years*?

$ ______

1b. If you deposited *$200 each month*, about how much money would you have *after 20 years*?

$ ______

1c. *After 20 years*, about how much more money would you have if you deposited $200 each month compared to if you deposited $100 each month?

I would have about ______ times more money.

2a. If you deposited *$100 each month*, about how much money would you have *after 40 years*?

$ ______

2b. If you deposited *$200 each month*, about how much money would you have *after 40 years*?

$ ______

2c. *After 40 years*, about how much more money would you have if you deposited $200 each month compared to if you deposited $100 each month?

I would have about ______ times more money.

3. Which would lead you to have more money? (check one):

______ Depositing $200 each month for 10 years.
______ Depositing $100 each month for 30 years.

APPENDIX C

Condition: Current Account Balance

RETIRMENT SAVINGS: WILL YOU HAVE ENOUGH?

Based on your total account balance, are you saving enough to meet your retirement goals?

Total Account Balance $

Condition: Future Account Balance

RETIREMENT SAVING: WILL YOU HAVE ENOUGH?

Based on your estimated account balance when you retire, are you saving enough to meet your retirement goals?

Estimated Account Balance at Retirement $

This amount is based on your current account balance of $, continued annual contributions of $ (the amount made by you and your employer over the last 12 months), and your age. Assumption: Retirement age of 65, 8% annual return, 3% inflation rate. Estimate is in today's dollars. Taxes are due upon withdrawal. For illustrative purposes only.

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