

idea comes from paleomagnetic analyses of lunar samples (8–10), which suggest that an ancient lunar magnetic field, comparable in intensity to Earth's present field, persisted for several hundred million years. This long duration is difficult to explain by an Earth-like dynamo driven by thermal or chemical convection (11), but recent work has revived the idea, suggesting that an ancient lunar dynamo could have been powered by differential rotation between the Moon's core and mantle, either continuously over several hundred million years (12) or for short periods after giant impacts (13). Broad magnetic anomalies over several Nectarian-aged (from 3.92 to 3.85 billion years ago) impact basins, recorded by slow cooling over long time periods, are also evidence for an early lunar core dynamo (14). However, it is also possible that the highly magnetic impactor remnants were magnetized by transient impact-generated fields (6) long after they were deposited. As these ephemeral fields are strongest at the impact antipode, this idea explains the intriguing correlation between some of the largest magnetic anomalies and the antipodes

of the four largest young impact basins on the Moon (15).

As the largest and oldest impact crater in the solar system, the SPA basin is of immense importance and is a strong candidate location for future sample-return missions. Although the detailed geologic record of Earth's formative past was erased long ago, the Moon preserves materials in its crust and mantle that date from before continents grew and life began to stir on Earth. The huge SPA impact brought deep lunar materials to the surface, and sampling these otherwise inaccessible rocks could hold the key to understanding how the Earth-Moon system formed and evolved. Moreover, an accurate absolute age for the basin would provide a vital anchor for interpreting the violent bombardment history of the Earth and Moon and its influence on the evolution of life on Earth. If Wieczorek *et al.*'s hypothesis is correct, a sample-return mission to SPA's northern rim may also uncover ancient meteoritic material from the giant asteroid that formed the basin itself. And if this highly magnetic material is accessible,

it could prove an invaluable resource for human colonization of the Moon.

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## SOCIAL SCIENCE

# Experimenting with Politics

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In his 1909 presidential address to the American Political Science Association, A. Lawrence Lowell (1) advised the then-fledgling discipline against following the natural scientists into greater use of experimental designs. This attitude toward experiments was still dominant at the end of the World War II, when political scientists were using increasingly intricate statistical methods to characterize relationships, but still ran few experiments. The tide began to turn in the 1980s, when scholars started to integrate the accumulated knowledge of traditional political science with the theoretical approaches of psychology and economics. This trend generated more acute causal predictions, which, along with technological developments, led political scientists to increasingly turn to experiments. Today, experiments are often the preferred method

to explain the causes and consequences of political behaviors (2).

Political scientists commonly use three different experimental methods. Laboratory experiments place subjects in situations that show how people reach decisions as voters, jurors, or legislators. Political scientists also embed experiments in large, and often nationally representative, surveys. These



**Your opinion counts.** In survey experiments, political scientists explore how the attitudes, perceptions, and emotions of citizens affect their responses in opinion surveys.

Social scientists are turning increasingly to experiments to explain important political behaviors.

experiments elucidate how variations in the descriptions or presentations of political phenomena affect the perceptions and feelings of diverse citizen populations. Finally, in field experiments, researchers integrate random assignment into real political campaigns or attempts to implement policy. These experiments can clarify the relative effectiveness of various tactics and strategies.

Laboratory experiments can, for example, inform the design and effectiveness of governmental institutions. In a classic laboratory experiment by Ostrom *et al.* (3), each subject decided how much to withdraw from a group fund that mimicked a scarce environmental resource. If the subjects overwithdrew, then the group as a whole earned less. Allowing group members to shame those who overwithdrew, or to shame and fine, yielded greater collective benefits than did fines alone. The results challenged the long-standing presumption that a group's ability to produce high-value public goods—such as good air quality for all, despite individual incentives to pollute—requires an external author-

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ity to impose punishments for noncompliance. The work stimulated a large body of research into when and how common political factors, such as ethnic heterogeneity in politically salient groups, affect the possibility of effective self-governance in the absence of external coercion (4).

Survey experiments (see the first figure) are particularly valuable for clarifying voter behavior. For example, Kuklinski *et al.* (5) used a “list experiment” to elicit the extent to which citizens are willing to admit racial anxiety or animus. Subjects were presented with a list of items and asked, “How many of them upset you?” Some received a three-item list; others received a four-item list where the added item was “a black family moving in next door.” Among white survey respondents in the American South, the four-item group reported an average 2.37 items that made them upset, compared to 1.95 items in the three-item group. Given that the groups are otherwise identical, the implication is that 42% of southern respondents  $[(2.37 - 1.95) \times 100]$  were upset by the thought of a black neighbor. This finding contrasts with non-southerners who reported that a similar number of items made them upset regardless of whether they chose from the list of three or four items. It also is telling that just 19% of southern respondents admitted that a black neighbor would upset them when asked the question directly.

Survey experiments can also provide a window into how people will think if policies are described in different ways. Schuldt *et al.* provide a compelling example in their study of one of the most debated issues of our time: climate change (6). The authors randomly assigned some survey respondents to answer a question about whether “global warming” has been happening. Other respondents were asked a version of the question that replaced the words “global warming” with “climate change.” The authors examined how the wording differences affected response patterns among politically relevant subpopulations. For example, 60% of Republican respondents believed climate change to be occurring, whereas only 44% of them believed global warming was taking place. Collectively, such experiments give users of surveys the means to more accurately interpret existing survey responses, and also provide unique data on the extent to which stated attitudes are robust to situational variations.

For decades, traditional opinion surveys have shown that many citizens cannot recall seemingly basic political facts, such as which political party controls a majority of



**Political power.** Political field experiments have provided insight into effective voter mobilization strategies.

seats in the U.S. Congress. Academics and members of the press, in turn, drew broad claims about voter incompetence from such data (7). Experimental research has produced a different view (8). For example, Lodge *et al.* (9) studied how citizens’ memories of specific candidate attributes affect their subsequent preferences. After asking respondents to report their opinions on a set of issues, the researchers gave them a fact sheet describing the issue positions of two candidates. After a randomly determined delay of between 1 and 31 days, 80% of respondents failed to recall candidate issue positions. Yet, most respondents expressed strong preferences for the candidate who most closely shared their positions. Common “political fact tests” may thus reveal very little about how voters think.

In a more recent related study, Prior and Lupia (10) asked 1200 selected members of a national survey to answer a set of fact-based political questions. They randomly assigned some respondents to a control group that mimicked traditional surveys. In a second group, respondents were paid 1 dollar for every correct answer. Relative to the control group, payment produced a 32% increase in correct answers for respondents who reported following politics “some of the time” (rather than “most of the time” or “not at all”). Thus, opinion surveys may underestimate what voters know because they offer little motivation for respondents to think about the questions during the interview.

In recent years, field experiments have gained greater visibility, particularly in the context of voter mobilization (see the second figure). A leading example is that of Gerber and Green (11), who randomly distributed messages—for example, through personal contact, by phone, or by mail—

to potential voters during an election campaign. Compared to voters who received no reminder or a mail or phone reminder, a personal visit boosted turnout. More recently, Gerber *et al.* (12) performed a study in which some subjects received a message that their neighbors would be informed about whether they turned out to vote. These subjects were much more likely to vote in the election than were subjects who received no message.

Findings from these voter mobilization experiments have affected the manner in which political parties conduct campaigns (13) and have been used as a model for inquiries about the effectiveness of voter mobilization strategies. For example, researchers in China showed that during a regional election in 2003, door-to-door canvassing to encourage people to vote increased turnout by over 10% (14). In another study, researchers randomly assigned 49 Indonesian villages to one of two methods for choosing an economic development program. In roughly half of the villages, chosen citizen representatives made the decision. In the other villages, all eligible villagers could vote directly on which program to pursue. The experimental treatment had small effects on the villages’ chosen projects, but villagers who were given the opportunity to vote viewed the chosen projects as more valuable and were far more satisfied with the outcome (15). Collectively, these efforts reveal effective routes to increasing electoral participation in ways that lend legitimacy to electoral outcomes.

The studies described above and others like them have transformed political science into a discipline in which experiments are increasingly seen as a preferred method of discovery and inference. Yet, important challenges persist in expanding the domain of experimental political science. One such challenge is that typical experimental subjects often lack the experience needed to act “as if” they were professional legislators; yet, legislators themselves are often reluctant to participate in experiments as subjects. Another challenge is that politics entails not just debates about the empirical consequences of choosing one policy over another, but also disagreements over basic values. Experiments have less power to settle such questions. Nevertheless, many aspects of modern politics follow a logic that can be evaluated scientifically. Political science experiments are increasingly helping researchers and citizens around the world to better understand how humans organize themselves.

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## MATERIALS SCIENCE

# Swell Approaches for Changing Polymer Shapes

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Most machines work by moving rigid elements or frameworks. In some cases, flexible elements, such as membranes, are attached to the framework and are passively deformed by its motion. In contrast, octopuses, hearts, caterpillars, and growing mushrooms are examples of natural structures made of soft tissue that move or change configurations through a completely different mechanism. Each element of the tissue—cells or compartments—undergoes some sort of active deformation, such as swelling, that creates stresses within the structure. The entire structure changes shape to relieve these internal stresses. Such control of shape and motion by active deformation has not yet been implemented into engineering design technique because of theoretical and experimental difficulties. On page 1201 of this issue, Kim *et al.* (1) present a technique for the production of gel sheets that are patterned into regions that can swell to different extents and actively deform into three-dimensional (3D) shapes.

A body that undergoes nonuniform growth or swelling is likely to contain residual stresses; the swelled components no longer fit together. Because the elements are “glued” together, they will be locally deformed (for example, if just one side of a sheet swells, it will bend into a U shape). For more complex structures, it is not easy to predict the final swelled shape (global configuration) of the body or to design a distribution of swelled elements to create a desired global configuration.

How can one construct soft material to undergo the desired, nonuniform swelling?

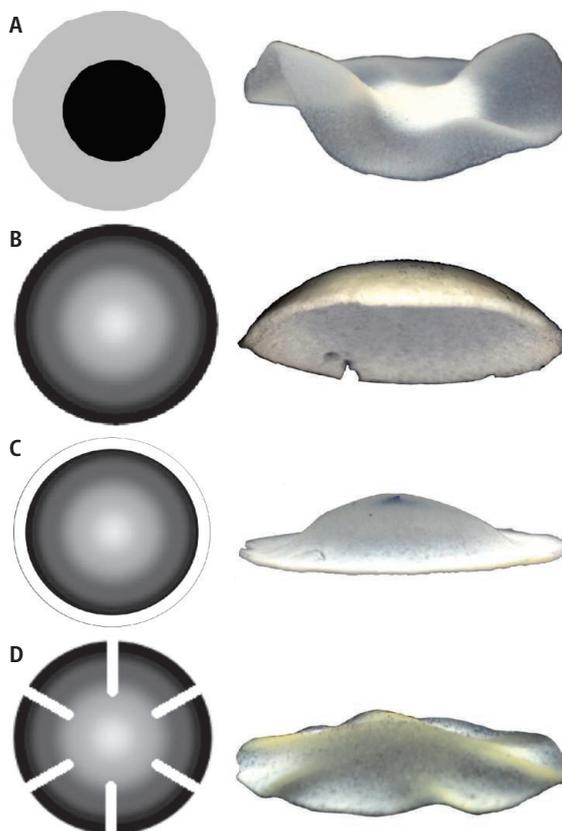
During the past decade, there has been progress in both theoretical modeling and experimental realization of shaping by active swelling. The research was focused mainly on the study of thin elastic sheets. In particular, non-Euclidean plates (NEPs) (2) are thin sheets that undergo some lateral growth or swelling that is uniform across the thickness of the plate but varies with location within the plate. If we consider a network of points in the sheet and the edges connecting them, the set

Patterning of cross-linked regions in polymer gel sheets with ultraviolet light creates unequal stresses and drives their buckling into complex three-dimensional shapes.

of edges in the swollen state undergo unequal distortions (defining new “reference states”) and will no longer lie in a flat plane but will buckle into a 3D configuration. The theory of NEPs uses the framework of differential geometry to express the reference lengths and the energy of such sheets, allowing the calculation of equilibrium configurations of NEPs.

Kim *et al.* constructed NEPs from gel sheets made of *N*-isopropylacrylamide (NIPAm), a hydrogel that reduces its volume when heated above 33°C (3). Ultraviolet (UV)–induced cross-linking of selected regions of the gel led to differences in local swelling: Swelling or shrink-

**Shape-shifting sheets.** Examples of masks (left) and the resultant buckled NIPAm gel sheets (right) are shown. In these macroscopic-scale examples (5 cm in diameter) the local “gray level” of the mask determines the amount of UV irradiation onto different regions of the sheet. Illuminated regions have greater cross-linking density, which decreases their shrinkage ratio. The presence of regions that undergo different amounts of shrinkage creates a 3D shape once the plates are activated in a hot bath. (A) A dark center region leads to an enhanced shrinkage in the center and the formation of a wavy disc. (B) A continuous gradient of gray scale can be tuned to construct a spherical dome shape. Small changes of the mask in (B) in the form of a clear ring along the margins (C), or six radial clear lines (D) leads to different modulations of the spherical dome. Samples were made by I. Levine at The Hebrew University of Jerusalem.



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