Inner Workings: Legos in the lab

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Vincenzo Vitelli is a condensed matter physicist who plays with blocks. “I play with Legos more than most kids,” he says.

Vitelli’s creations crowd together on pegboards and platforms in his office at the Lorentz Institute at the University of Leiden in The Netherlands. They invite interaction: Push on a lattice that looks like basket weave, and it barely shrugs. Nudge a free-hanging block on a chain-like structure, and its sets off a cascade that travels like a wave from one end to the other. Plastic bins filled with loose blocks, sorted by color, occupy nearby shelves. “There’s nothing simpler than Legos,” he says.

In his hands, Legos are no mere playthings. Vitelli uses the blocks to build physical representations and models of abstract concepts. He refers to his research as “topological mechanics,” encompassing both classical concerns and insights into quantum systems that appear in condensed matter. That means that his colorful, complicated structures have deep mathematical roots. The process of designing, building, and manipulating such Lego models can be powerful, he says, not only for demonstrating an abstract idea but also for unveiling unanticipated insights.

Vitelli researches how the structure of “soft” materials, like sand or foams, affects its physical

properties. Soft matter research is an interdisciplinary field that spans chemistry and physics, and even pertains to some biological materials. Not all of those researchers speak the same language, but they can hold all blocks in their hands.

By turning mathematical abstractions into Lego creations, says Vitelli, scientists from a range of disciplines can start to understand what’s going on in the model. “If we want to describe an idea to engineers or experimental physicists, we can show them the phenomenon and let them hold it, to give them a clear idea of what we’re talking about,” he says.

Such models also allow discovery, says Vitelli. “You can play with it and see properties of a structure that may seem counterintuitive

Vincenzo Vitelli works with Legos to bring theoretical physics principles to life. Image courtesy of Vincenzo Vitelli (Lorentz Institute, University of Leiden, The Netherlands).

Using Legos, Vincenzo Vitelli built a tangible demonstration of what he calls the “spinner” phase of motion. It exhibits motions key to the operation of mechanical devices, such as windshield wipers and robotic arms, in which some parts move while others necessarily remain stationary. Reproduced from ref. 2.

when you’re only looking at equations,” he explains.

Case in point: Vitelli saw a paper, published in the January 2014 issue of *Nature Physics*, on a special type of lattice proposed by Tom Lubensky and Charles Kane, physicists at the University of Pennsylvania. Theoretical lattices are useful in modeling everything from the crystal structure of a solid to magnetic properties to architecture (1).

The lattice Lubensky and Kane described would allow movement on the surface but not in its interior. In practice, this means someone could wiggle an outer rod, but the interior would remain stationary. Mechanisms that allow only certain movements and prohibit others are crucial to the operation of many devices, whether windshield wipers or robotic arms.

The two researchers reported that their lattice shared its unusual behavior—as well as some key equations—with a topological insulator, an exotic material that conducts electrons on its surface but not in its interior. That connection suggests their lattice connects classical, Newtonian physics to the bizarre properties of the quantum world.

Vitelli and his team read the paper and immediately thought of Legos. “Can we build this?” they wondered. In a paper published last September in PNAS, Vitelli and his colleagues demonstrated their physical version

of the lattice, a chain of colorful plastic blocks held together with rubber bands (2).

They built more models, and when Vitelli and his team played with the contraptions, they identified behaviors that had not been predicted by the equations. For example, when they tilted the chain on its side and let gravity tug on the links, the motion that had been confined to the edge flip-flopped through the whole device (see movies S1–S9 in ref. 2). “In our hands, it moved however it wanted. It wasn’t constrained by any mathematical simplification,” he says. That freedom pointed to a new avenue for investigation (see https://www.youtube.com/channel/UCrCu-LgraCW8VBsf3g_dUTw for example, “Topological linkages II: flipper driven by gravity”).

Lubensky and Kane were impressed with Vitelli’s work. “His models were really quite remarkable because they have the property we discussed in our paper,” says Lubensky. Also, as a bonus, “it was even richer than he—or we—thought.”

Vitelli is now thinking about applications. His models require a nudge to start moving, which usually comes from a human hand. He’d like to incorporate small motors to do that work instead—this might make the models useful for robotics or active materials. He’s also using Legos and 3D-printed models to study stability and failure in materials. In the May 11, 2015, issue of PNAS, he and his team used physical models to demonstrate a new material that, under stress, buckles only at locations predetermined by the designers (3). Such a material might be used, for example, to design structures that shatter in controlled, safe ways. He also thinks that this approach—building in defects—might point to a new way to store information.

Whatever concepts he tackles, Vitelli says he will apply both equations and toy models. “They become a demonstration when you show it to others, but they can be used to discover new things,” he says. “Building models blurs the line between how somebody approaches things mathematically and experimentally.”

1 Kane CL, Lubensky TC (2014) Topological boundary modes in isostatic lattices. *Nat Phys* 10:39–45.

2 Chen BG, Upadhyaya N, Vitelli V (2014) Nonlinear conduction via solitons in a topological mechanical insulator. *Proc Natl Acad Sci USA* 111(36):13004–13009.

3 Paulose J, Meeussen AS, Vitelli V (2015) Selective buckling via states of self-stress in topological metamaterials. *Proc Natl Acad Sci USA* 112(25):7639–7644.