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Making calculus tangible

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I will present two of our current efforts at Oregon State towards making calculus (both integral and differental) more concrete for middle-division physics majors. In electrostatics, our students find challenging integration over charge densities using spherical and cylindrical coordinates. We encourage them to think of integration in terms of "chopping, multiplying and adding." In order to better facilitate the development of this understanding, we have incorporated into our curriculum a computational lab course, in which students write programs to numerically solve problems similar to those they are tackling analytically in class. By the end of the junior year, students encounter thermal physics, in which partial derivatives and total differentials play an important role. These derivatives require mathematical concepts that are typically new to students, while involving physical properties such as entropy and temperature that are themselves conceptually challenging. In order to facilitate mastery of the mathematics of partial derivatives, we introduced the Partial Derivative Machine, which is a mechanical analogue of thermodynamics, and enables students to grapple with the mathematics of total differentials and partial derivatives in a more tangible context.