BOARD # 195: STEM Education for K-12 and First-Year College Students: Gummy as a Pressure Sensor

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STEM Education for K-12 and First-Year College Students: Gummy as a Pressure Sensor

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Abstract

In this study, we present an innovative approach to STEM education for K-12 and first-year college students using readily accessible materials to demonstrate fundamental principles of pressure sensors and capacitance. Our educational module employs gummy candies and marshmallows as dielectrics to create simple pressure sensors, facilitating interdisciplinary learning and transform that bridges abstract scientific theories and practical applications. We measured the capacitance changes by applying pressure with a 200g weight or a finger press on three types of gummies and marshmallows, revealing a correlation between the softness of the materials and the percentage increase in capacitance. By grounding complex concepts in tangible experiments, the module aligns with constructivist learning theory, enabling students to directly observe the relationship between physical deformation and electrical property changes. This hands-on approach enhances students' understanding and interest in STEM fields, providing a promising model for engaging and cost-effective education. Furthermore, our approach underscores the potential of using everyday materials for effective STEM education, promoting critical thinking and problem-solving skills.

Keywords

STEM education/ K-12/ college students/ Pressure sensor/ Interdisciplinary learning / Experiential learning

Introduction

In an era dominated by rapid technological advancements and an increasing reliance on digital and engineering solutions, the importance of Science, Technology, Engineering, and Mathematics (STEM) cannot be overstated [1], [2]. The cornerstbegin nurturing a future workforce adept in these areas begins with early education in K12 through first-year college students. This instills not only the necessary knowledge base but also a passion and curiosity for these fields. It has been established that students' attitudes toward their educational and career paths begin to form in the early stages of their schooling. Integrating engineering education in K-12 and early stages of college students can significantly expand students' career perspectives, offering them a broader array of opportunities [3], [4]. Given the need for engaging and accessible STEM educational strategies, along with the vital role teachers play in cultivating a passion for science and technology, addressing the challenges of implementing engineering programs in K–12 education is important. These challenges include teacher’s lack of confidence in their abilities and a shortage of available resources to effectively support such curriculum initiatives [5], [6]. In this context, we introduce a simple and unique hands-on approach for interdisciplinary learning in STEM education by utilizing gummies and marshmallows, accessible materials in daily life, to teach the principles of pressure sensors and capacitance changes **(Figure 1)**. This method serves as a bridge between abstract scientific theories and their practical applications, making the learning process more relevant and stimulating for students. The use of everyday materials in demonstrating scientific principles follows the constructivist learning theory, which posits that knowledge construction occurs best through hands-on experiences and reflections on those experiences [7]. By engaging in this simple experiment, students not only learn about basic science and engineering concepts but also potentially develop critical thinking and problem-solving skills essential for their future academic and professional endeavors.

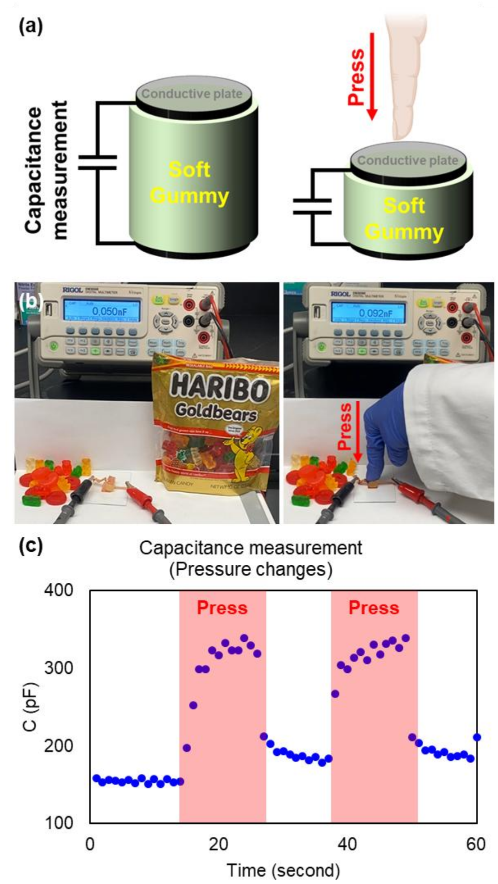

Figure 1. (a) Illustration for the soft gummy pressure sensor between conductive plates to measure capacitance changes when pressure is applied. (b) The representative experimental setup with Haribo Goldbear gummy candies, where the gummy's capacitance is being measured by digital multimeter before and during pressing. (c) Graph plotting capacitance as a function of time, highlighting the capacitance increase when the gummy is pressed.

Methods

We demonstrated a simple pressure sensor using five products with varying levels of softness, all of which are readily accessible to students **(Figure 2(a))**. The products tested (each costing less than $15) included three types of gummy candies: Life Savers, which are high softness **(Figure 2(b))**; Haribo Goldbears, of medium softness **(Figure 2(c))**; and Sour Patch, which are low softness **(Figure 2(d))**. In addition to these, we used Jet-Puffed marshmallows **(Figure 2(e))** and Elmer's Gue glassy clear slime **(Figure 2(f))**. To measure the capacitance, we placed conductive plates above and below each product. Although any conductive material can serve as the conductive plate, we opted for copper foil tape due to its high conductivity, affordability (costs less than $10), and ease of use, as it can be easily cut to the desired size. For the demonstration and plotting of the measured capacitance, the Rigol DM3058E Digital Multimeter was used **(Figure 1(b,c))**. But a handheld digital multimeter (AstroAI, ~$20) can also be used to simply measure the capacitance between the two positioned copper tapes **(Figure 3(a))**. A 200g weight (several pieces of calibration weights, ~$10) was used to apply pressure on the top of a simple gummy pressure sensor **(Figure 3(b))**, proving that everyday school supplies or household goods can be utilized for this project. We could also successfully demonstrate the clear capacitance changes using just a finger press, without the need for any other tools **(Figure 3(c))**. This module experiment's design not only works well for individual education, it costs about

Figure 2. Materials and preparation with conductive tapes for capacitance measurement. (a) Five product packages used in this experiment. Three different types of gummy candies. (b) Life Savers. (c) Haribo Goldbears. (d) Sour Patch. (e) Jet-Puffed marshmallow and (f) Elmer's Gue glassy clear slime.

$55, but it can also be used for group projects that encourage teams to work together by obtaining various kinds of gummies and distributing them. This could be a more cost-effective and experientially rich approach to STEM education.

For high school and college students, explanations of scientific principles like [A] may be appropriate to aid understanding or to extend their knowledge but may be difficult for younger students. For kindergarten to middle school students, using an analogy such as [B] may make it easier for them to understand and help them visualize the concept in their imagination. The following examples are explanations for definitions of capacitance:

[A] Capacitance, a fundamental concept in electrical engineering and physics, is the ability of a system to store charge per unit voltage. This experimental module examines the impact on capacitance by applying physical pressure and varying the distance between two conductive plates. For parallel plate capacitors, the capacitance is given by the formula $C=\varepsilon * (A/d)$, where C is the capacitance, ε is the permittivity of the dielectric material, A is the area of the plates, and d is the distance between the conductive plates. Dielectric material is an insulator that can be polarized by an electric field, meaning it can align its charge in a direction. Permittivity determines how much electric potential energy is stored in a dielectric material per unit volume in the presence of an electric field. In this experiment, gummy candies along with marshmallow act as dielectric materials. When pressure is applied to the gummy sensor, a decrease in d leads to an increase in C.

[B] The analogy of a sponge can be used to explain the concept of dielectric material. Imagine two sponges made of the same material. Depending on the density of the inside porous structure, the sponges have different levels of softness. When the same pressure is applied to both sponges, the softer sponge which has a more porous structure will compress more than the stiffer sponge with less porous. Consequently, this leads to a different level of increase in capacitance.

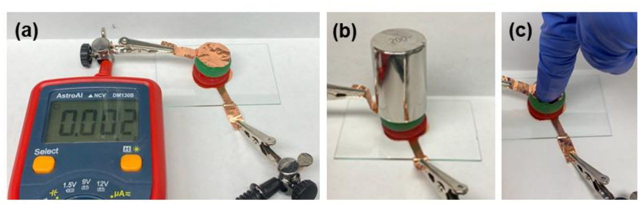

Figure 3. (a) Capacitance measurement using a hand held digital multimeter. (b) A 200g weight is placed and (c) finger press is applied on the top of gummy pressure sensor.

Results and Discussion

We conducted experiments on five materials with varying levels of softness to test their efficacy as pressure-sensitive dielectrics in a simple pressure sensor forced by 200g weight or finger press. Capacitance changes between the conductive copper tapes were recorded using a digital multimeter. We first quantified the change in capacitance resulting from a 200g weight applied to two gummies. As depicted in **Figure 4(a)**, the Life Savers, which feature high softness, showed an approximately 150% increase in capacitance when the 200g weight was applied. In contrast, the Sour Patch, which features low softness, exhibited a smaller capacitance increase of around 25%, as shown in **Figure 4(b)**. The lower percentage change indicates that the Sour Patch is less compressible than the Life Savers, resulting in less deformation and, therefore, a smaller change in the distance between the conductive plates under the same pressure on the Sour Patch.

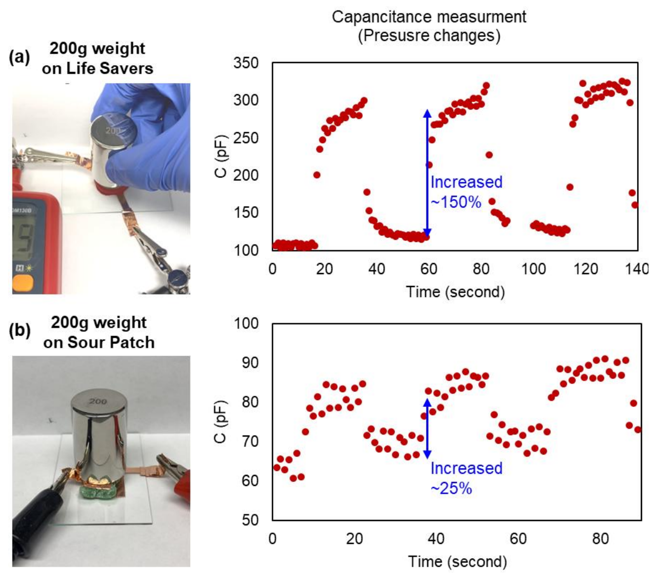

Figure 4. Capacitance response to placed 200 g weight on (a) Life Savers gummy and (b) Sour Patch gummy.

Upon being finger pressed, as shown in **Figure 5(a)**, the Life Savers pressure sensor exhibited a substantial increase in capacitance from 150 pF to 350 pF, indicating an approximately 200% increase in capacitance. This corresponds to significant changes in the shape of the gummy with a noticeable reduction in the distance between the two conductive plates as pressure is applied. The Haribo Goldbears exhibited an approximate 100% increase in capacitance values, rising from 60 pF to 120 pF upon pressure application, as illustrated in **Figure 5(b)**. This indicates that the Haribo Goldbears have less deformation due to their firmer texture, compared to the softer Life Savers. When analyzing the data collected by each pressure sensor using three different types of gummies as dielectric materials, a correlation can be identified between the sensitivity of the capacitance changes and the softness of the gummies. As shown in **Figure 5(c)**, the marshmallows' airy and compressible nature allowed for a considerable change in thickness upon pressure application, impacting the capacitance values. The measured capacitance values and sensitivity using Jet-Puffed marshmallows showed a similar trend to those obtained with Haribo Goldbears, peaking at around 120 pF. However, when inferring the softness of the materials by touch, the softness of Jet-

Puffed marshmallows is akin to that of Life Savers rather than Haribo Goldbears. Considering that the abovementioned correlation applied between the gummies does not align with this observation, it is believed to be due to intrinsic differences in the permittivity of the dielectric materials between gummies and marshmallows.

However, Elmer's Gue glassy clear slime is conductive and cannot function as a dielectric material. This property made it impossible to conduct capacitance measurements. The clear capacitance changes upon implementing direct pressure indicate the potential of these materials as dielectrics. Generally, our observations reveal that the softer the material, the higher the percentage increase in capacitance value, which correlates with the dielectric layer becoming thinner more easily under pressure.

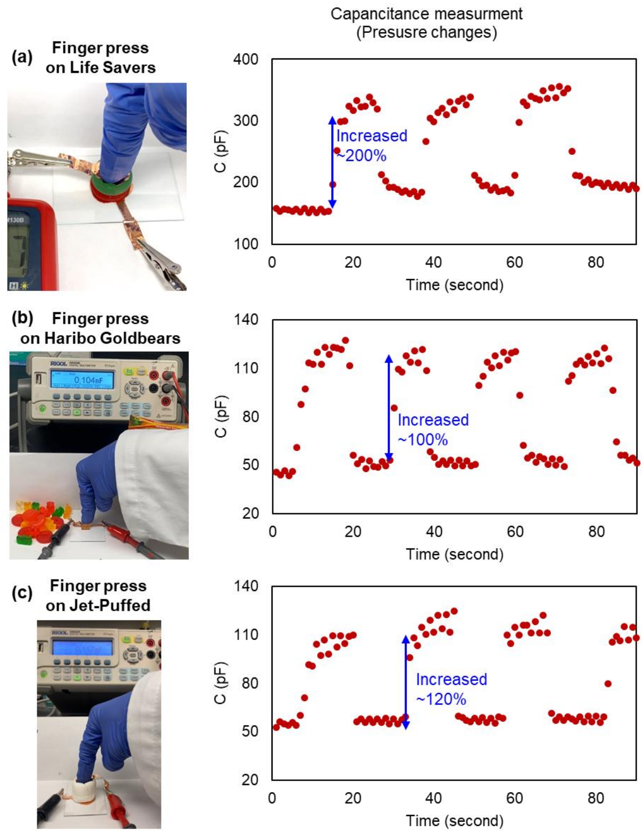

Figure 5. Capacitance response to finger pressure on (a) Life Savers gummy, (b) Haribo Goldbear gummy, and (c) Jet-Puffed marshmallow.

Conclusions and Outlook

Our interdisciplinary educational module has demonstrated that using readily accessible gummy candies and marshmallows as materials for simple pressure sensors can help to demystify the complex principle of capacitance for students. The hands-on approach of applying pressure to these materials allows for direct observation of the relationship between physical deformation and electrical property changes. The interactive nature of the experiments with novel methodologies not only aids in understanding fundamental concepts in electrical engineering and materials science but also encourages critical thinking about the role of material properties in the small system.

In future work, the pedagogical strategy of this project will focus on standardizing materials for more controlled experiments, allowing students to predict and then observe the outcomes based on the softness of the materials. For instance, using the previously discussed capacitance formula, $C=\varepsilon * (A/d)$, we can determine the permittivity of the dielectric material for each distinct gummy by conducting controlled experiments with the same conductive plate area (A) and gummy thickness change (d). This will allow us to verify the relationship between the permittivity and the softness of the gummy material. Before conducting the experiments, students can have a group discussion to hypothesize the results. By conducting the experiment and analyzing the outcomes, students can verify their assumptions and engage in critical thinking to contemplate the reasons and implications. The goal is to foster an interdisciplinary engineering education environment that emphasizes hypothesis-driven inquiry and scientific exploration. We believe that by engaging in the new methodology, students can be exposed to the opportunity to experience an aspect of the engineering thought process. In the future, similar strategies will be applied to STEM education, extending concepts such as additive manufacturing of soft materials [8] and the functional applications of soft electronics [9][10].

Ultimately, we believe this module may reinforce the importance of experiential and interdisciplinary learning in the acquisition process of scientific knowledge. By grounding abstract theories in practical experiences, we significantly enhance educational values for K-12 and first-year college students, potentially influencing students' future career paths in STEM fields. Our initiative serves as a promising model for making STEM education more accessible and enjoyable, setting a foundation for a technologically proficient society and suggesting the direction of transforming engineering education.

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