# "FINGER KITS:"
## An Interactive Demonstration of Biomaterials and Engineering for Elementary School Students

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From personal computers to cell phones, there is no dispute that technology developed by scientists and engineers greatly influences the lives of U.S. residents. Despite the increasingly important influence that science and engineering have on our lives, however, the numbers of undergraduate and graduate degrees awarded in these areas to U.S. students have decreased steadily for the past several decades.[1] In addition, the numbers of women and minorities in this field remain low compared to our nation's demographics (*e.g.*, New Mexico is now a minority-majority state). [2] For these reasons, many efforts have emerged with the goal of attracting students into engineering and science disciplines, including outreach efforts such as those sponsored by the National Science Foundation.

The authors of the present work include researchers from both the University of New Mexico (UNM) and the University of Washington (UW). The technical expertise of the authors is in the field of biomaterials, or the interaction of man-made materials with biological systems. The term "biomaterials," therefore, encompasses a number of research interests including microbially induced corrosion of ship hulls, the development of DNA microarrays, and the optimization of materials used for biological implants. While it is unlikely students in the fifth grade (the target audience of the following demonstration) are familiar with DNA microarrays,

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**Also affiliated with Albuquerque Public Schools* many have already been exposed to implanted materials, as they or members of their families may have contact lenses, use a glucose monitor for their diabetes, or have hip or other implants. Therefore, giving students a project that emphasizes biomaterials taps into something with which they already may be familiar and that is becoming increasingly important in the lives of millions of people around the world. As noted by Tobias,[3] tying science to societal issues via cooperative and interactive learning styles may increase participation by women and other under-represented minorities in science and engineering. Furthermore, as more people are going to be affected by biomaterials, there will be more opportunities for exciting, rewarding jobs in the field of biomaterials. It has been estimated that by the end of this decade, there will have been more than a 30% increase in bioengineering-related employment positions.[4]

To capture part of this excitement, we present a real-world problem to the student: Someone has an injured finger joint, and the students in the class need to design an implant to replace it. After presenting the problem, we discuss how the students could go about making a replacement finger joint. In order to do this, the students need to understand what comprises a finger. Next, the students have to consider what materials are available that match the properties of the components in a finger. As this is an engineering project, we ask students to develop design goals for the finger (*e.g.*, that it is flexible, bends only in one direction, is able to pick up an object).

At UNM, we made a number of adaptations to the original design. For instance, to better communicate with the bilingual and monolingual (Spanish-only speaking) students within the Albuquerque Public School (APS) district, we translated the text used in our brief presentation into Spanish and recruited Spanish-speaking volunteers. Furthermore, our participating volunteers are typically a combination of undergraduates, graduate students, postdocs and faculty to show representatives of women and minorities that have gone on to successful engineering careers. This hands-on activity engages the students' creativity while also teaching them a basic understanding about what biomaterials are and how one would go about designing and building them.

## BEFORE THE VISIT

Prior to any outreach events, the following should be addressed: 1) provisions of key ideas and vocabulary necessary to understand the lesson, 2) assembly of kits, and 3) training of volunteers.

### *Vocabulary*

To achieve the first task, our outreach coordinator (co-author Stanton), when scheduling outreach visits, provides teachers and principals with vocabulary words and concepts necessary to understand the lesson. Table 1 presents the key vocabulary that the outreach director (co-author Canavan) and elementary school teacher (co-author López) discussed prior to the first UNM visit to López's classroom. These vocabulary words are also defined early in the interactive talk portion of the visit to reinforce these concepts before more difficult matter is discussed. In addition, each of the visits is scheduled such that it follows instruction on the human body. Table 2 identifies the parts of the body especially important when considering restoring the function of the finger joint. While this is not a comprehensive list (*e.g.*, fingernail is not listed), these are the body parts that make primary contributions to the function of the joint, which is the focus of the lesson. For example, it is the contraction and expansion of the muscles that lead to joint movement, and bone which provides structural support.

### *Assembly of Kits—Materials*

Table 3 lists the contents to be included in each kit. No additional supplies are required to perform this activity. For each of the suggested materials (*e.g.*, chalk), a potential use in the finger kit design is listed (*e.g.*, bone). Therefore, each of the materials listed in Table 3 should approximate those of the human body listed in Table 2. It is important to note that we provide this list to aid volunteers using this demonstration, but we do not provide it to the students themselves. Also, we often see students find creative uses for the materials provided that we had not initially envisioned (*e.g.*, the use

**TABLE 1**
**Vocabulary given to 5th grade teachers prior to demonstration to prepare for visit.**

| Vocabulary word | Definition |
|---|---|
| Biology | The study of living organisms. |
| Engineer (noun) | A person who designs, builds, or maintains engines or machines. |
| Implant | A tissue or an artificial object in a person's body introduced by surgery. |
| Material | The substance of which a thing is made, such as wood, glass, or metal. |
| Prosthetic | An artificial body part, such as a leg or a heart. May be internal or external. |

**TABLE 2**
**Parts of the body taught in 5th grade module prior to visit by UNM.**
**Additional body parts may be added by students (*e.g.*, fingernail).**

| Part of the Finger | Function |
|---|---|
| Arteries and veins | Blood flow |
| Bone | Structural support, mechanical strength |
| Muscles | Contract and extend to move joints |
| Nerves | Sensation of heat/cold, movement of body via attachment to muscles |
| Skin | External surface of body |
| Tendons | Attach muscles to bone |

of a paperclip as a fingernail to make the finger aesthetically more pleasing, instead of as a structural element to hold the design together). Although most of the parts can be re-used (*e.g.*, pipe cleaners, straw, etc.) and the kits recycled through many events, at UNM each kit is used only once, and the students retain possession of their designs. Therefore, to maximize the number of students we can interact with over a year, the materials used in the finger kits are low-cost items that can be purchased in bulk (*e.g.*, Popsicle sticks vs. tongue depressors). We estimated that, when the contents of the kits are purchased in bulk (*e.g.*, to make 400 kits), the cost of the kits fall to ~$1/student.

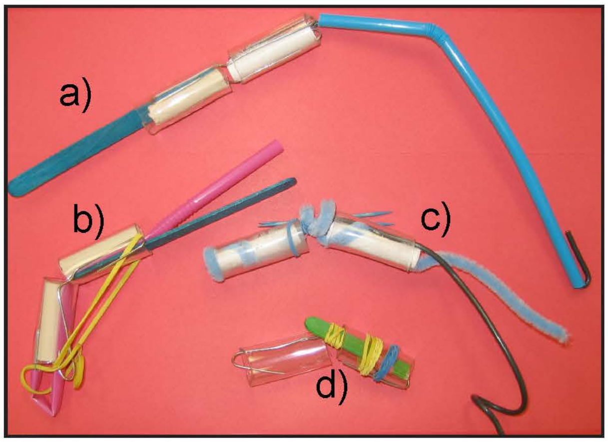


***Figure 1.** Examples of finished finger designs. Note that the resulting design will reflect the design considerations agreed to by the students at the beginning of class, as well as their own individual preferences. For example, design a) uses a Popsicle stick as a fingernail, while design d) uses it as a brace to prevent backward movement.*

### Training of volunteers

It is advisable to train all volunteers prior to the outreach "season" so they understand what to expect from the events. In particular, the volunteers should understand how the materials in the kit can be used in designs. Such an event will also yield a number of diverse designs (as illustrated in Figure 1), demonstrating to the volunteers that they may see many different ways the materials will be used by the elementary school students. Also, the volunteers should be briefed about what to expect from a visit to an elementary school, including any necessary information about the school's dress code. If possible, the teachers participating in outreach visits should be invited to speak with the volunteers about the general level of knowledge and understanding, as well as modes of learning, that young students demonstrate.

## DURING THE VISIT

The outreach visit contains several elements: 1) a brief presentation outlining the topic and project (~15-20 minutes); 2) discussion and formulation of the design and test parameters (~2-5 minutes); 3) fabrication of the designs by the students (~30 minutes); and 4) evaluation of the design according to the parameters previously outlined (~10 minutes). In addition, a fifth step (evaluation of the efficacy of the visits) may be conducted after the visits to allow for any modifications or improvements to be made as needed.

### Introductory Talk

At the beginning of the visit, the lead volunteer will give a brief talk[5] to introduce the range of topics in bioengineer-

**TABLE 3**

**Contents of the Finger Kit. Note that all materials are meant to be commonly commercially available and of low cost. Substitutions, deletions, and additions to the kit may be made to accommodate the preferences of the demonstrators, as well as the availability of material.**

| Qty | Item | Potential Use in Finger Design |
|---|---|---|
| 1 | Zip-close sandwich bag | None (used to contain other parts listed below) |
| 3 | Pieces of clear, flexible tubing: pieces ~1.5" long and wide enough for dowel pieces/chalk to slip into | "Skin" that holds all parts together |
| 1 | Tongue depressor/Popsicle stick | "Brace" to prevent fingers from bending backwards |
| 4 | Toothpicks | "Brace" to prevent fingers from bending backwards/sideways |
| 1 | Pipe cleaner | Actuator (muscle/tendon) or body part (blood vessel/nerve) |
| 1 | Piece of copper wire 10" long (~24 gauge) | Actuator (muscle/tendon) or body part (blood vessel/nerve) (muscle/tendon) or body part (blood vessel/nerve) |
| 1 | Flexible straw | Actuator (muscle/tendon) or body part (blood vessel/nerve) |
| 4 | Rubber bands | Actuator (muscle/tendon), body part (blood vessel/nerve), or to hold design together (tendons) |
| 3 | Wooden dowels, ~1.5" long x 0.25" diameter | Bones |
| 3 | Half-pieces of chalk | Bones |
| 2 | Small paper clips | To hold design together (tendons) or body part (fingernail) |
| 2 | Large paper clips | To hold design together (tendons) or body part (fingernail) |

ing, including examples of biochemical engineering (*e.g.*, pharmaceuticals and dialysis), biomechanics (*e.g.*, grafting procedures, prosthetics, and implants), and biomaterials (*e.g.*, contact lenses). These subjects, which were first introduced to the students using the vocabulary list (see Table 1), are used to lay the groundwork for the design students will be performing. Therefore, it is imperative they understand what the terms mean. It is important to remember that most fifth-grade students are (at best) unfamiliar with even the most basic language traditionally used in bioengineering, and often hold erroneous beliefs (such that the term "engineer" solely applies to people who repair car engines).

We have found that the best way to engage the students' attention and get these concepts across is to make the talk highly interactive, with the lead volunteer asking the students questions and listening to their responses. For instance, the students become quite animated when asked: "Do you know anyone who has contact lenses or hearing aids?" Such questions solidify ideas in the students' minds, as they are able to make connections between the new material and something they are already familiar with. In fact, according to elementary school teacher and co-author López, the most important factor for a successful demonstration is to pay attention to cues from the students to determine if they are understanding the material, and therefore connecting bioengineering to their lives.

Later in the talk, the materials used in biomaterials are discussed. In particular, there is significant emphasis placed on how the properties of a material are used to match a specific function. For instance, metal implants are often used in bone replacements (due to their mechanical strength), whereas flexible rubber would not be a suitable replacement. Also, the idea that a design may be perfected over time (such as the early use of ear trumpets prior to the invention of a hearing aid) can show students that rarely is a design "perfect" from its first prototype.

Finally, we use the talk as a chance to educate the students about the career path that bioengineers take, from their current position to college and graduate school. Many of our participating volunteers are from the local community (20% of UNM volunteers attended APS as students, and 78% of APS participants attended APS as students). As importantly, many volunteers are members of groups traditionally underrepresented in science and engineering (45% are women, and 50% identify themselves as Latino, Hispanic, or Chicano) and are Spanish speakers (35%).

### *Formulate Design and Test Parameters*

At the conclusion of the talk, the students are told they will not have to wait until college or graduate school to start their research career, and that they will be "bioengineers for a day." The students are told they will design a replacement finger and will test their designs according to parameters they agree upon. This leads to a discussion to elicit design goals from the students themselves. For instance, the volunteers may ask, "What do fingers do?" [They bend.] "Could you play the piano/push a doorbell if your fingers 'bent' in all directions?" [No, your finger would just bend backwards if you pressed on the keys/buzzer.] "Can you be more specific about how they should bend?" [In one direction only.] "What could you do to allow them to bend, but in just one direction?" [This is where students tend to start equating the materials to what actually makes up their fingers.] We have found that asking the students to come up with their own rubric for a good design is far more engaging than providing these parameters directly. In addition, this method requires higher-order thinking skills and often causes a great deal of excitement among the students. Figure 2 shows a page from a student's notebook that lists the design considerations students agreed a finger should have, as well as the parts of the body that should be included (mitiriols [*sic*]).

### *Fabrication of the Designs*

Once the design parameters have been agreed upon, the volunteers distribute the kits to the students, and fabrication of the designs begins. During this portion of the visit, the volunteers and teacher should circulate among the students. While we discourage the volunteers from telling the students how to make the design, they can provide guidance, reminding students about the parameters (*e.g.*, if the finger bends, but does so in many directions, it hasn't been optimized). If students are stumped, the volunteers can help provide prompts to get the students working on their designs. For instance,

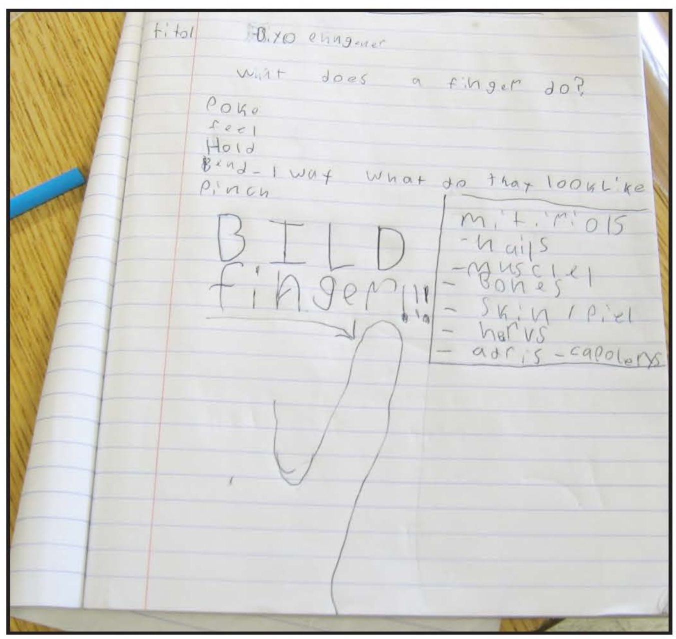


*Figure 2. Page from a student's notebook at Longfellow Elementary. The student has listed the design considerations the students agreed a finger should do, as well as the parts of the body that should be included (materials). She has also illustrated her own finger for the design.*

the volunteers can ask: "What body parts are in a finger? [Bone.] Is there anything in this kit that reminds you of that part? [Chalk or wooden dowel.] This also gives the students a chance to interact with their potential role models and ask them questions about themselves while they work on the designs. Furthermore, this gives the volunteers a chance to stress the creative aspects of science and engineering. In addition, the students often begin to observe the designs used by others to overcome a particular challenge (*e.g.*, the use of toothpicks as "braces" to prevent their design from bending backward) and incorporate it into their own. Such peer mentoring is a natural occurrence in this environment. Figure 3 illustrates each of these modes of learning during a visit from the UNM Biomaterials Engineering Outreach Program to Longfellow Elementary School.

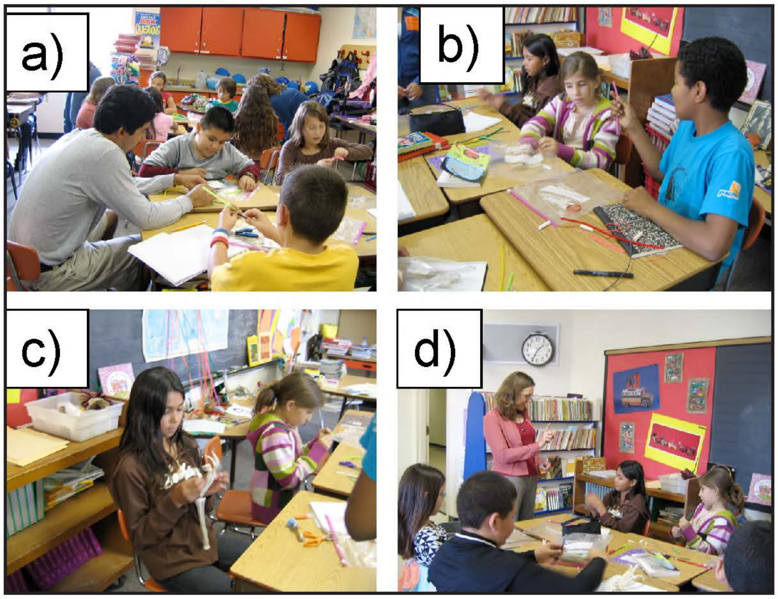


***Figure 3.*** *Examples of the different modes of learning during a visit to fifth-grade students at Longfellow Elementary School (Albuquerque, NM). UNM volunteers circulate throughout the classroom giving guidance and providing translation into Spanish, where necessary (a); students often teach each other lessons learned from their designs, a classic example of peer learning (b); a student consults the hand of a skeleton to determine the parts of the finger (c); the students' teacher reminds the fifth-grade bioengineers that one criterion of their design is that it must bend (d).*

### *Evaluation of the Design*

At the end of the visit (or in a post-visit session with their teacher), students evaluate their designs according to the parameters to which they previously agreed. Table 4 is an example of a rubric designed by the students in co-author López's fifth-grade class, including the design parameters (or criterion) considered important by the students, as well as their standards for the design. For example, the students considered the ability to hold something up as an important criterion, and a design that is capable of holding up a pencil in the middle section of the finger may be considered an advanced design. Often, the students come up with new designs or improvements not initially listed as criteria in the rubric. For instance, some students will attempt to improve the aesthetics of the design by including a paperclip as a fingernail. The volunteers and teacher may then remind students that many designs are improved over time for aesthetic reasons (*e.g.*, less noticeable dental fillings and hearing aids).

## AFTER THE VISIT

The design evaluation is considered the final stage of the formal visit, and the students are allowed to keep their designs. As well, some teachers may want to display the top designs or keep them for follow-up. In most cases, students from the classrooms we visited sent "thank you" letters to the demonstrators, relating what they learned, how much they enjoyed

**TABLE 4**
**Example of a rubric used to evaluate the students' designs. Note that the criteria used will vary to reflect those that are proposed and agreed upon by the students at the beginning of the demonstration.**

| Criterion | Emergent (1) | Nearing proficient (2) | Proficient (3) | Advanced (4) |
|---|---|---|---|---|
| Moves like a finger. | Doesn't move. | Moves somewhat, but in too many directions that are not appropriate. | Moves forward. | Moves forward, not backwards. Does not move to side; only the whole finger can move side to side. Has two places where it can bend. |
| Has components of a finger. | Has components that don't function like a finger. Components are not in the right place. | Has only two components: possibly bone and muscle or skin and bone. Components may not be in the right place. | Has bone, skin, muscles, and fingernail. Components are generally in the correct place. | Has bone, skin, muscle, fingernail, capillaries, nerves and other sensors. Components are in the correct place. |
| Holds something up (e.g., pencil). | Doesn't hold it up at all. | Barely holds it up—falls quickly. | Holds up pencil. | Holds up pencil in the middle section of finger. |

**...the hands-on "finger kit" demonstration addresses a number of benchmarks from the State of New Mexico[6] as well as the Project 2061 Benchmarks for Science Literacy (from the American Association for the Advancement of Science, AAAS), after which many states have modeled their standards.[7]**

the visit, and their interest in science. The letters are always appreciated by the volunteers, and help reinforce the value of outreach activities to them. In addition, it is also a chance for the outreach organizers to get valuable feedback. For instance, due to the large number of students who mentioned in their letters how much they wanted to keep their designs (to show their parents or siblings, or to improve on the design), we at UNM now make kits for each student, rather than attempting to recycle them (as had been done previously).

## EXPECTED IMPACT

As previously stated, one of the primary complaints that elementary school teachers have about outreach projects is that they are often considered stand-alone demonstrations with little thought to how they will be integrated into the regular curriculum. As it is described above, the hands-on "finger kit" demonstration addresses a number of benchmarks from the State of New Mexico[6] as well as the Project 2061 Benchmarks for Science Literacy (from the American Association for the Advancement of Science, AAAS), after which many states have modeled their standards.[7] The individual benchmarks pertaining to the fifth grade are outlined below.

### *NM Benchmarks Addressed*

Strand I/Standard I/Benchmarks I & II (Scientific Thinking and Practice): By observing and experimenting on their model, and analyzing their product (using the rubric), the students learn to understand the scientific method. In addition, the students learn to communicate their findings during the class discussion at the end of the event, and learn that their conclusions are subject to peer review.

Strand II/Standard I/Benchmarks II & III (Physical Science): By addressing how the muscles of the finger work and discussing the energy source that makes fingers move, this project addresses the state benchmark pertaining to forces and motions. While studying the action of muscles and tendons on the finger joint, the students learn that when a force acts upon an object, it will move in a different direction.

Strand II/Standard II/Benchmark III (Life Science): By addressing the purposes of the finger joint (in relation to replacing that function using a prosthetic), the students learn the properties, structures, and processes of living things, and how cells and tissues are related to the behavior of an entire organism.

Strand III/Standard I/Benchmark I (Science and Society): With its emphasis on how machines have been engineered to aid in human health (*e.g.*, glucose monitors, hearing aids, etc.), the introductory talk demonstrates to students how technology has affected the lives of individuals. Emphasizing how rudimentary prosthetics have evolved allows students to understand how scientific discoveries, inventions, practices, and knowledge are influenced by individuals and societies. Furthermore, in an integrated elementary curriculum, the progress of bioengineers could be connected to the effect on social issues.

### *AAAS Benchmarks Addressed*

Benchmark 1B (The Nature of Science/Scientific Inquiry): Developing the rubric to evaluate their designs allows students to learn that scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments.

Benchmark 1C (The Nature of Science/The Scientific Enterprise): Discussing their results reinforces to students that clearly communicating their results is an essential part of doing science. Because the volunteers participating in this event are both men and women of many different ages and backgrounds, it is reinforced that people who perform scientific work come from all populations.

Benchmark 3A (The Nature of Technology/Technology and Science): As they learn to design replacement finger joints, students learn that technology extends the ability of people to change the world, often in response to the need to meet basic survival needs.

Benchmark 3B and C (The Nature of Technology/Design Constraints and Systems and Issues in Technology): While building their designs, the students rapidly grasp the need to match properties of materials and engineering principles while designing solutions to problems. Simultaneously, the students learn about design tradeoffs. For instance, the finger design with the best side-to-side stability may aesthetically be the least pleasing.

Benchmark 6C (The Human Organism/Basic Functions): As they learn how nerves stimulate the muscles in a joint to contract, the students learn how the human body functions as a system—with the brain giving signals to the body to stimulate movement.

Benchmark 8F (The Designed World/Health Technology): By learning about prosthetics and designing a replacement body part, students learn that technology has made it possible to repair and sometimes replace some body parts.

Benchmark 11A (Common Themes/Systems): By learning about how the materials in their kits (and the parts of the body) work together as a system, students learn that the parts of a system influence each other and may not work well if they are broken, worn out, or misconnected. This is applicable to both their own creation as well as the body part it is meant to replace.

Benchmark 12C (Habits of Mind/Manipulation and Observation): By asking the students to relate the material properties of the objects in their kits (*e.g.*, chalk) to those in the human finger (*e.g.*, bone), the students learn to choose appropriate common materials for making simple mechanical constructions and repairing things.

## CONCLUSIONS

This work describes one hands-on activity and demonstration developed at UW and further refined at UNM. The goal of the project is to provide a hands-on experience with an engineering project. While the project itself is goal-oriented, it is also creative and open-ended, with many possible solutions to the problem presented. In this way, the creativity involved in the project is emphasized, rather than only relying on science and math ability. In our experience, the demonstration works best when it is tailored to suit the needs of the community, and we recommend that anyone adopting this outreach demonstration take the time to do so with their own community. It is for these reasons that we at UNM chose to focus our activities on one grade level (5th grade) in one school system (APS). Furthermore, the specific needs of the community (*e.g.*, bilingual students in NM) should be addressed (*e.g.*, translation of the slides into Spanish). Finally, we chose simple, low-cost materials to maximize the number of students that can be reached with the activity. Ultimately, we strove to develop a fun experience that will get students excited about career opportunities in science and engineering. After all, although not all students will ultimately pursue science and engineering-related careers, we feel that a general population more educated in the area of science and engineering is also a valuable pursuit.

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