Embodied Engagement with Scientific Concepts: An Exploration into Emergent Learning

Arlette R. C. Baljon, Joseph W. Alter and Marilee J. Bresciani Ludvik

ABSTRACT
In response to an invitation to integrate science and art pedagogy, science and dance students enrolled in specific disciplinary courses, collaboratively produced choreography based on scientific principles. This paper reports students’ experience of this process. Science students reported an increased understanding of concepts, while dance students found inspiration for choreography within scientific concepts. Tensions and misconceptions were evident in the process with respect to disciplinary language, the notion of scientific thought, and the level of physical awareness. The relationship between movement and forms of knowledge production in science was investigated as well. The paper ends with recommendations for future classes.

Introduction
Two instructors designed a common curricular component for their classes on Polymer Science and Dance Making. They deliver it twice and then researched the outcomes. This was made possible by San Diego State University’s (SDSU) Arts Alive initiative, which provided financial and logistic support. The initiative creates opportunities for students to engage in the arts as an integral part of a comprehensive education that promotes creative research, interdisciplinary collaboration, professional innovation, and personal enrichment. Among the many responses to this initiative was the development of an interdisciplinary curriculum that brings together faculty and students from art and science departments. The hope is that the result is a transformative educational experience, which fosters the understanding of artistic practices as a mode of critical inquiry. Art and science are often perceived as polar opposite disciplines, with the former producing intuitive and conceptual and the latter exact and physical understanding. Stereotypes persist concerning the learning dispositions and personalities of students and professionals in both fields, which among others challenged the instructors to design this novel curricular component.

They are not alone: recently there has been a strong interest to integrate art into science disciplines. Such STEAM (Science, Technology, Engineering, Art, and Mathematics) efforts seek to integrate art into the training of professional scientists.

Neuroscientists have found that infusing art into science disciplines promotes knowledge retention and creative problem solving (Immordino-Yan and Damasio 2007). STEAM programs are also used in science outreach to recruit minority students and to create events that make science accessible to learners of all ages. A recent review by Segarra et al. discusses the role of performing arts like dance in STEAM programs (2018). Even before proposing and designing the curriculum discussed in this paper, the instructors organized a workshop with an expert from one of the programs mentioned in this review (STEM Dance-ology).

Our approach fundamentally differs from a STEAM approach, though. Our goal was not only to explore how art can be used to enforce and explain the scientific method and train scientists, but we aimed for a truly multidisciplinary approach that also challenges assumptions made by scientific doctrines and that demonstrates how science can generate concepts that inspire intriguing dance choreography. We set out to teach students to look at ideas from multiple perspectives in order to be able to translate from conceptual domains to physical action as well as convert physical phenomena into conceptual modes.

CONTACT Arlette Baljon abaljon@sdsu.edu Department of Physics, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, USA.
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In this qualitative study, we first express our motivation as instructors to engage in this type of interdisciplinary instruction. Then the planning and delivery processes for this experience are described in detail, which is followed by the findings from the student focus groups and a discussion of them. Finally, we provide recommendations.

The motivation of instructors in personal narrative form

To allow the perspectives of the instructors to become transparent, each of them provides a personal narrative below. These include their motivation to teach collaboratively and expand their personal experiences with teaching disciplinary content.

Arlette Baljon (Physics): When told about the Arts-Alive initiative, I was immediately “on board”. I have always wondered how we scientists come to understand the laws of the universe. I do not believe in the myth of disembodied objectivity as the foundation of robust inquiry. Often, an intuitive vision informs the choice of experimental investigations. Such a process assumes the scientist and/or science student as active participants. However, science aims to eliminate the human aspects of the theories it accepts. It prefers mechanistic theories of matter, often presented in a mathematical framework. Even though this may be the official scientific language, a deeper look into practices and “ways of knowing” reveals that imagination and bodily knowledge are integral to science. (Kounios et al. 2008; Myers 2015).

Great scientists often have profound, sudden, and sensual experiences that provide them with insight, leading to a breakthrough in their research: so-called “aha-moments” (Zajonc 2006). Barbara McClintock, who received a Nobel Prize for her work on genetic transposition in corn, is often cited claiming, “I just know about genes and corn in an internal way and then placed my understanding in the frame of science”. This claim is often interpreted as her claiming she sensed and experienced the corn. Evelyn Fox Keller writes, “Somehow, she placed herself in their feet” (1983). Given such first-person experiences are important for scientific discovery, I was wondering how bodily experiences help students to learn scientific concepts in the classroom. After all, Indigenous people have traditionally used dance to approach and understand nature. In particular, I liked to investigate if students obtain a deeper conceptual understanding of the dynamics of polymers by moving their bodies. Hence, Joseph Alter seemed the perfect partner.

Joseph Alter (Dance): Dance has traditionally been created and structured through “relationships” to musical or theatrical conventions or, in the case of the Judson Church “post-modernist”, through the negation of those relationships. That seemed, to me, extremely limited. I first became interested in using science to inform Dance Studies in 2002 as a graduate student at The Ohio State University. There was tremendous pressure to “justify” dance through the lens of interdisciplinary studies: the prevailing notion was that dance, being a largely non-verbal art form could not “speak” for itself and therefore must look to other disciplines for the means by which to explain it. This struck me as intuitively incorrect - dance could “speak” for itself if only we could understand more deeply its language. This led me to study “embodied cognition” as the first step in a journey that has branched into many unexpected places as well as convinced me to radically rethink pedagogy and curriculum.

I became interested in investigating how other disciplinary research methodologies and perspectives might influence choreographic processes- investigating alternative perspectives of how natural phenomena self-organize, how systems influence one another, and what emergent properties might arise from their adaptation to choreographic practices. As I have found these investigations very fruitful in my development as an artist, I felt it was imperative to introduce Dance Majors to this area of inquiry.

The learning design process

Arlette and Joseph started to discuss using scientific concepts to inform dance choreography back in 2008. Their official collaboration started in Fall 2016 when they organized the workshop mentioned in the introduction. In addition, during the 2015-16 AY, several physics students volunteered to meet with the dance company to explore collectively which physics concepts might be able to inspire a dance. They created a dance, called “Strange Attractors”, which in scientific chaos theory stands for “a set of positions and velocities toward which a system tends to evolve regardless of the starting conditions.” This dance was well received within the dance community and selected through adjudication for the American College Dance Association Conference Gala Performance. Both activities helped Arlette and Joseph to become familiar with each other’s disciplines and motivated them to submit a proposal for a collaborative teaching project which was selected by the Arts Alive competition the following year. They proposed to co-create a science and dance class as an entirely new way to explore
scientific concepts – a class based on intuition, creativity, and human experience and for which learning science supported its efficacy (Zull 2002; Bresciani Ludvik 2016). They did not suggest abandoning mathematical tools in the teaching of science; they simply hoped to systematically expand the scientist’s toolbox with new sensual approaches to connect to and increase understanding of nature. Moreover, they hoped to expand the toolbox of the dancer by showing how scientific content can be used to inform choreography. The relevant learning outcomes are shown in Table 1. To compensate for the design time involved, the instructors each received one class release.

In the Spring semesters of 2018 and 2019, Arlette and Joseph taught the “Polymer Science” and “Dance Making” courses collaboratively. Students each enrolled in one of these classes, but not in both. The “Polymer Science” class counts as an elective in some science and engineering degrees; the “Dance Making” class is a required class for all dance majors. Note that these classes do not count for general education and both have prerequisites. Before enrolling in “Polymer Science,” students need to take “Thermodynamics”. Before enrolling in “Dance Making,” students need to take “Modern Dance”. The approach is fundamentally different from a “linked course” approach which creates learning communities by requiring the same cohort of students to enroll in two common general education courses (Margot et al. 2013). Both approaches require significant preparation and close collaboration between instructors. However, unlike in linked courses, the students enrolled in SDSU Arts Alive classes meet with both instructors simultaneously. Hence, Arlette and Joseph would alternatively lead the discussion in class and thereby often complement each other’s instructions.

Each disciplinary class was taught as usual most of the time. The 14 science students learned about the structure, syntheses, physical properties, and utilities of polymers and biopolymers. The 13 dance students learned about the compositional, generative, and performance aspects of dance making. However, unlike previous years, these students spent nine 50-minute class sessions together for this collaborative experiment (as well as some time outside class). The time together replaced a literature study and final presentation for the science students and helped dance students brainstorm for choreography concepts. Only a fraction of the students’ grades were based on the shared project; the bulk of it remained based on performance in their respective disciplines. The science students were primarily seniors in chemistry, engineering, or physics; the dance students were freshman and sophomore dance majors.

The nine shared sessions were structured as follows. The first three sessions were devoted to basic exercises in choreography that related interactions and movement and helped students to become familiar with each other. Moreover, all students were introduced to science concepts that the instructors judged optimal as basic principles for dance choreography – such as formation, structure-property relations, and memory of polymers. Later in the semester, students spent more and more class time in small interdisciplinary groups of 5 or 6 to work on their dance choreography. Initially, they were asked to come up with a few possible scientific concepts and how these could inform choreography. This “proposal” was presented to the other groups. Afterward, each group chose a specific topic and worked on a five-minute presentation. The choreographies were shared with an audience of friends and colleagues. Both science and dance students performed. However, the instructors made it very clear that they were not looking for esthetic fluid motion, but for scientifically motivated choreographic principles. The presentations were followed by a discussion with the audience.

The study

The purpose of this qualitative study was to explore how students experienced this intentional design

| Table 1. Learning outcomes. |
|------------------------------|
| An increased curiosity in the field that is not their primary focus. |
| A mind that has the capacity to attend to and consider multiple perspectives. |
| The ability to translate and apply ideas from conceptual domains to physical action (from the theoretical to the physical). |
| The ability to translate physical phenomena into conceptual modes (from the physical practice to theoretical models). |
| The ability to successfully engage in group problem solving through cooperation and a shared responsibility and mutual respect for both difference and sameness in their respective artistic and scientific disciplines/culture. |
| The ability to comprehend and articulate in writing, and through movement an understanding of critical thinking in both embodied and conceptual forms. |
| An increased ability to ‘reframe’ questions from multiple perspectives and to promote innovation in their respective domains of knowledge. |
| An enhanced ability to ‘ideate, generate, and articulate’ strategies for communicating knowledge to their peers, in their discipline, and in their communities at large. |
| The ability to investigate, through new perspectives, one’s “home” discipline. |
process and to ascertain whether learning emerged. The research questions were:

1. How did students experience this course?
2. How well did the course design enhance students' learning?

To aid data collection and analysis, Marilee Bresciani, an educational research methodologist, was brought in to conduct the focus groups. Following IRB approval, she designed interview protocols for the focus groups after a conversation with each instructor. Their perspectives were included in the protocol design, which was used during the student focus groups. These were conducted following the conclusion of the course and video-taped with students' signed consent. In addition to the focus group transcripts, instructors analyzed learning experiences in reflective papers, which were assigned as a part of the course itself. These remarks were not in response to specific prompts. Rather, these reflections on their learning emerged in an authentic way via the invitation of the instructors.

Students were divided into three focus groups of eight or nine students. One focus group consisted of all dance majors, another of all science majors, and the third was mixed. Of the 25 (out of 27) students that participated in the focus groups, 5 were Hispanic/Latinx, 2 Asian, and the others Caucasian. Moreover, 14 students identified as female and 11 as male; however, 8 of the male and only 5 of the female students were in the science class. Students ranged in age from 19 to 28.

Data analysis of transcribed videos and reflective papers used axial and open-ended coding. Themes emerged through constant comparison. While the videos were rich with interesting notations – dancers, for example, often acted out their responses to the interview questions while the scientists sat in their chairs and responded with facts first and then experience – only the written transcripts were ultimately analyzed.

Findings

The transcript data analysis resulted in the four findings summarized below. Several statements support each of the findings; these statements are marked either from a student enrolled in Polymer Science (science) or Dance Making (dance). The first finding relates to the difficulty students had understanding each other across disciplines. The second relates to the traditional role experiential knowledge plays in artistic and scientific modes of inquiry. The third finding inquires as to whether sensual approaches like movement can help students learn about scientific concepts. The fourth informs how scientific perspectives might influence choreographic processes.

Understanding across disciplines

Science and dance majors entered this learning experience with widely different assumptions and points of reference. For instance, scientists believe that there is only one correct answer to a question (e.g., one correct representation of nature); after all, most often a test question has only one correct answer. On the other hand, dance students are accustomed to ambiguity and the fact that there are many ways to represent a concept through movement. In the collaborative choreographed experience, science students were focusing on phenomena in the world and dance students on the self-other relation. Both sets of students became used to very different languages during their disciplinary course work. They lacked a common academic jargon to connect these varying epistemologies. The instructors had been meeting frequently for several years, during which they slowly built a common vocabulary. Scientists tend to reason through abstract formulas. Dancers, on the other hand, express themselves through movement. The students, therefore, had a hard time finding the words to fill the gap between the disciplines. They bridged that gap successfully by using visuals. The students’ quotes shared below illustrate this:

(dance) I did not realize these fields are so different. We would say, what are you talking about?

(science) It helps us understand science words and concepts. It helps that they created also a more visual representation. They came up with a covalent bond as “holding hands.”

(dance) I learned how smart dancers are because we had to work collaboratively as a team and figure things out. I think people do not understand that there is not always a right and wrong answer. We found common ground and did build from that.

However, students did see the positive side in working through these differences

(dance) Doing a project like this you have to be open-minded. We are not that comfortable. It teaches us to be open-minded, to be adaptive.

Moreover, some science students were more visually oriented than others.
I am more like a kinaesthetic learner, so I like to use my hands when I learn concepts.

The traditional role of experiential knowledge in dance

Dancers and scientists approach nature fundamentally differently. Dancers seek to experience nature as nature and to experience nature within themselves. They work iteratively: first they “ask a question,” then they experience themselves in the examination of the question (from a state of equanimity or non-judgment); they subsequently reflect and analyze their experience and reengage with the question by introducing a perhaps better question, after which the process repeats. They consider movement a form of nonrepresentational “knowing and/or discovering,” where “knowing” is embodied. In short, as Joseph Roach (2015) writes in the foreword for “What a Body Can Do”: “A body can mind.” In their paper on enactive cognition, Haosheng, Hong, and Endeng (2019) discuss a new approach to embodied cognition based on the assumption that there exist human cognitive processes that do not make any appeal to internal representational or computational states. The more imaginative, mystical, and experiential definition of “truth” which dancers embrace – although not unheard of long ago – starkly contrasts with the scientific “truth” we have come to accept during the last several centuries. For scientists, nature exists outside them; they practice objectivity, broker knowledge, and arbitrate the truth. The following statements from students capture this:

As a result, science students were more focused on the end product (a dance on a scientific concept), while dance students tended to focus on the process of creation itself.

As scientists, we need to be consistent. What should we do? What does it mean? It has to be accurate, but expressive as well. To be able to combine these two opposite perspectives is the challenge. Ok, we need an end product, but it does not matter how we get there.

We make a dance just to remake it. Just to fix it again. Just to say we do not like it. That is the kind of work we are into. We try doing things; experience setbacks; and then try it again. We do not look back at the end product but look at the steps/pathway.

The dance majors were more extroverted and the science majors were more reserved. They were open to ideas but it was hard for them to come to action.

Learning scientific concepts through movement

Many science students believed that the class was a transformational experience for them. They even mentioned that participating actively in animating forces and relations between molecules helped them to better understand science.

Before this class, we were more likely to understand the concepts and structures from the description or pictures from the textbook, which means that we were receiving the information passively. However, when we are embodying scientific concepts, we have to express our understanding subjectively, and this deepens the impression of the knowledge. Embodying the concepts also taught me that there is no wrong way to express your understanding using your body. I used to think objectively, and I thought there would always be one correct answer in the world of science. However, the dancers taught me to think subjectively and there is no fixed way to present the concepts, phenomena, and structures in our dance.

What really struck me is how artistic science can be. Not just what we already know. It is not about learning here but more about creative insight. You put yourself in the position of the molecules.
(science) Engineering has such a strict foundation for what is considered correct. The boundaries we are allowed to cross are limited as to what is possible for a given environment. Dance making and art have open boundaries and even if crossing them is considered wrong, the end result might turn out to be something beautiful. Think of talented artists. Do they follow the rules of what is conventional? Engineering needs to consider a creative concept while also maintaining the balance of being within technical correctness.

(science) Furthermore, I would say that the embodying of some science concepts can complement the formal study of science. It would not replace it because the math part of the science will still require some calculations and derivations on paper. Moreover, problem-solving sometimes demands the traditional way of studying. However, the conceptual part of science will one hundred percent benefit from this innovation.

(science) I didn’t expect to come from this experience of creating a dance gaining a better understanding of polymer science than I had already gained from our in-class sessions. But surprisingly, working out how to move our bodies in a way to portray a polymer’s behavior in certain situations actually accelerated my understanding of the topics themselves. It was as if the ideas that I had learned on paper were alive and in front of us. This entire experience has really opened my mind to the many paths of learning there are both in our university and in the world, and to the idea that there is no singular experience when it comes to education. The wonder of learning can come in many different forms, each unique and important in its own way. The real magic is sharing these experiences with one another and keeping the learning alive.

( science) Lastly, while taking this class as a future chemistry high school teacher, I was able to see how science can be explained to children in a way that all types of learners can understand. In teaching, there is the universal design for learning concept, which states that lessons need to be designed in a way that all students are able to learn. I was struggling with this concept because I did not know how science could be taught to children who have no interest in it at all, but this class showed me: I need to think outside of the box. Art and science can go hand in hand, and one can be taught through another that way, so all students gain from learning.

However, a few science students disagreed.

( science) I do not think there was any sort of net gain: beneficial or not beneficial for us from teaching scientific concepts to dance students.

( science) I think I have a good understanding of the scientific concepts and movement is not beneficial for reinforcing the concepts. It is difficult to teach a concept with physical movement.

( science) I think the dance is a very avant-garde method of approach. Everything communicated was abstract, not concrete.

**Dance choreography based on scientific concepts**

Although the dance students tried to use the scientific principles to explore and inspire choreographic thought, most science students focused on directly translating the scientific concept into choreography. This disconnect was hard to overcome during the limited time they spent together.

(dance) Our dance was showing how bonds form polymers. We just went from single-ourselves-and then made a bond with someone by having our arm around them.

( science) So we had this idea to talk about bond formation. When I was trying to explain the different kinds of bonds, I realized that it’s more about pockets. So, are we able to show the dancers the difference between these kinds of bonds? We actually stood up with them and said, “Okay, you are going to hold this hand”. So maybe we did not talk about electrons and transfer, but they still got the picture.

(dance) This is what happened: We started the process, and the scientist would say, “All polymers repeat!” and then the dancers would think, “How can we create a dance from that? What are the possibilities?” And then we would actually create the dance. We wanted it to be accurate to make the science people happy.

(dance) We had to take back stuff. The science students wanted to do exactly what polymers do. We wanted to take it a little bit further. But we could not do that because of the structure they wanted to follow. If we would have had a longer collaboration, we would have been able to explore this difference more thoroughly.

Moreover, science students complained about the background of the dance students.

( science) We are simply met with a lack of experience. Most parties should have more time invested in each other's fields. So the scientists should focus more on the dance theory behind it. And, within the capabilities of the dancers, they should have received more instruction on the science involved. The instructors already selected an umbrella of topics, but it would have been beneficial if we could have been able to build on these topics.

**Summary and discussion of findings**

Dance and science majors participated in innovative courses to support emergent learning that included an assignment to collaboratively choreograph a short dance based on scientific principles. Despite many
obstacles, the majority of students within both groups valued the learning experience. Both groups were driven by a similar curiosity and a wish to order information about the world around them. They experienced friction in how the two disciplines—science and dance—explore the natural world. Scientists construct objective theories extensively relying on mathematics to capture the “truth” of the universe’s mysteries (Falk 2019; Frank, Geisler, and Thompson 2019). Hence it is no wonder that science students insist that the deepest truths about reality and life can only be revealed through a scientific approach that aims to construct objective knowledge independent of the culture and worldview of the observer. In this sense, it is evident that the prescriptive learning ecology was at play (Collins and Halverson 2010).

Dance, on the other hand, serves to connect to the universe in a ritual and ethical way by gathering individual subjective experiential knowledge of nature’s mysteries and needs (Evans 2020). The complex-adaptive learning ecology is likely at work here (Mitra and Dangwal 2010). Both groups of students recognized this divide and the science students were challenged by the dance students to reconsider these assumptions. They first struggled with and then started to appreciate an embodied approach to learning and robust inquiry. They acknowledged that the artistic approach helped them to understand and remember concepts, as has been suggested in the literature (Immordino-Yang and Damasio 2007). By looking at science from the perspective of molecules, they came to appreciate that all “knowing” is embodied. However, one can, for the purposes of making distinctions regarding the “qualia of states of knowing,” use the terms Conceptual Knowledge and Embodied Knowledge. Conceptual Knowledge employs symbolic language, e.g. mathematics. Embodied Knowledge on the other hand has distinct qualia: it deals with an “ineffable knowing” that language only points to.

Interestingly, the students’ learning process findings mirror those of Myers’ study of crystallographers’ learning process. Myers (2015) performed ethnographical studies of crystallographers in the field of structural biology and protein modeling and discovered that all of these scholars relied on their moving bodies to reason through the molecular structure of a complex biological molecule and make sense of the molecular realm. Like our students, Myers’ scholars learned how to feel through structures by experimenting with the forces and tensions in their own bodies. Unlike the traditional approach in which science is understood as an objective, rational, and disembodied practice, their bodywork seems to be a form of knowing and mode of thought.

Similarly, our findings mirror what we understand to be true about learning. Zull (2002) and Bresciani Ludvik (2016) illustrate that emotion is a part of learning, that movement enhances learning, and that reflection and creativity abound when multiple ways of learning can be introduced, particularly with adolescent learners (ages 10–25). When we consider the role of emotion in emergent interdisciplinary learning, which seeks to combine seemingly disparate ecologies of learning, we recognize that more opportunity for dialogue and exploration must ensue (Williams, Karousou, and Mackness 2011). We hope that then students can focus on resolving potential communication problems and misunderstandings. (Nilson 2010).

**Recommendations**

In retrospect, this class design and implementation were very ambitious. The collaboration took place as part of two disciplinary courses and, as a result, students spent only approximately 12–15 hours together over the entire semester since required disciplinary course content could not be dropped. Most students mentioned that, given the large divide between the disciplines, they needed more time to develop a common framework. This student observation is echoed in research about emergent learning subjects (Williams, Karousou, and Mackness 2011). A new learning ecology must emerge after combining two disciplinary subjects. One way in which this could be accomplished is by offering classes entirely focused on this interdisciplinary process. We envision that two faculty members teach these classes simultaneously. Before the first offering, it is essential that faculty receive assigned time to discuss details of the collaboration. Moreover, it is crucial that faculty are able to spend time to become familiar with each other’s disciplines and teaching styles. Teaching a class together is demanding and requires many adjustments. Arlette and Joseph each received one course release time.

We recommend that during the first half of the semester, students are introduced to each other’s disciplines and familiarized with each other’s disciplinary language and belief systems using a variety of problem-based learning pedagogical practices that appeal to each discipline (Nilson 2010). Students may benefit from discussions in small interdisciplinary groups as they seek to understand the scientific concepts, how to work with them, and proactively solve problems in the way that they interact with and learn from each other. Changing the composition of the discussion groups will allow them to meet classmates...
they may not ordinarily meet. In addition, it is important that, during this period, the instructors select together a set of teaching materials (content-related, applied learning-related, and assessment-related) for students to work with. These can be introduced to the class as a whole.

In the second half of the semester, students should be assigned to permanent groups to work on the artistic product. We recommend that they have the opportunity to show and/or perform their product to friends and the campus community at the end of the process. This demonstration of learning could be combined with an open discussion about the students’ experiences.

Interdisciplinary collaborative learning which seeks to create an emergent learning ecosystem will likely help both science and non-science students in their future careers and as concerned citizens. We live in a time of increasing distrust toward the scientific community. According to Kabat (2017), trust might be regained when scientists adopt a less authoritarian attitude and when they would acknowledge what they do not know instead of presenting a dogmatic truth. Classes like the one we present here may enable non-science and science students to enter into a collaborative problem-solving dialogue that is intertwined with, not removed from, nature and the human condition. Future scientists would learn how to incorporate embodied experiences to deepen their knowledge and retention of concepts. Art students, on the other hand, would learn to use science effectively as inspiration for artistic experience. Both would hopefully experience a renewed sense of wonder at academic discovery and recognize that creativity and knowledge production are interconnected. After all, there can be as much esthetic beauty in a physical theory as in an artwork.

ORCID

Marilee J. Bresciani Ludvik [ORCID: http://orcid.org/0000-0003-3829-5804]

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