Contemplative practice and classical electrodynamics: Discovering electromagnetic phenomena in lived experience through somatic meditation

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1 Introduction

One of the objectives of the undergraduate physics curriculum is for students to develop an awareness of the connections between formal physical principles and personal experience [1]. However, data from surveys administered to measure changes in students’ beliefs about physics shows that awareness of connections between the abstract and the experiential tends to deteriorate, sometimes significantly, following instruction in undergraduate physics courses [2, 3]. Although this phenomenon has been discussed extensively in the literature, and preliminary studies have indicated that addressing students’ beliefs about physics with specific teaching practices can have measurable effects [4], few pedagogical interventions have been designed or implemented to address this particular weakness in undergraduate physics instruction [5, 6, 7, 8].

In this work, we show that a contemplative practice consisting of a somatic meditation followed by a contemplation expands students’ awareness of the connections between formal physical principles and personal experience by deliberately drawing their attention to electromagnetic phenomena in their surroundings. In this process, students also naturally recognize interdisciplinary connections between electrodynamic principles and chemical and biological systems. We also find that the contemplative practice inculcates a sense of curiosity and an intrinsic motivation to deepen their understanding of electromagnetic theory, as well as an appreciation for the somatic, affective, and cognitive benefits of a contemplative practice.
2 Method

2.1 Contemplative practices in higher education

Contemplative practices, which hold a central place in many spiritual and philosophical traditions, are characterized by a deep, introspective exploration of one’s personal experience in the present moment. Such practices take a wide variety of forms, including meditation, mindfulness, t’ai chi ch’uan, yoga, and the contemplative arts. Over the last several decades, empirical studies within the emerging field of contemplative sciences have shown that contemplative practices—meditation in particular—can have substantial benefits in secular contexts. In clinical psychology and medicine, for instance, mindfulness-based stress reduction (MBSR) and mindfulness-based cognitive therapy (MBCT) have had positive psychological and physiological effects on patients suffering from anxiety, depression, and post-traumatic stress disorder, as well as a range of chronic stress-related and pain-related conditions [9, 10, 11, 12]. The benefits of meditation have also been explored in diverse contexts such as sports [13], the workplace [14], and the criminal justice system [15, 16].

Meanwhile, contemplative practices are increasingly integrated alongside traditional pedagogical activities in educational institutions. In higher education specifically, meditation has successfully improved the social, emotional, and cognitive health of both students and teachers [17, 18, 19]. Contemplative practices have also helped support learning, creativity, and the discovery of personal meaning in course material [20, 21]. With the support of professional organizations, national and international conferences, and peer-reviewed publications, contemplative practices have been implemented in courses in the humanities, the social sciences, and the natural sciences [22, 23, 24], including biology [25, 26], chemistry [27], earth science [28], environmental science [29, 30], mathematics [31, 32], and physics [33, 34].

2.2 The contemplative practice

The contemplative practice developed in this work consists of a somatic meditation followed by a contemplation. In the somatic meditation, students are instructed to direct their attention into and throughout their bodies, gradually expanding their awareness into the surrounding space with the help of their senses. Students are then asked to contemplate manifestations of electromagnetic phenomena in their surroundings while maintaining a light somatic awareness. The handout describing the practice to students is included in the Appendix.
2.3 Implementation

The contemplative practice was integrated into three calculus-based courses in classical electrodynamics at Northwestern University. Two of the courses were aimed primarily at prospective physics majors, and one at students majoring in the engineering sciences. A total of 66 students completed the practice, of whom 15 were prospective physics majors. In each course, students were required to complete the contemplative practice for credit in the third week of a nine-week quarter. Following completion of the contemplative practice, students were asked to submit a written reflection on their experience. In order to encourage genuine responses, students were informed that the reflections would be graded on completion only.

2.4 Analysis

Student reflections were collected electronically, stored without personally identifying information, read, and coded. The coding procedure took place in two phases: in the first phase, common themes in the reflections were identified, and, in the second phase, phrases associated with each theme were labeled and catalogued. In order to ensure consistency, coding of student reflections was completed by one of the authors, and reviewed by another.

3 Results

3.1 Awareness of electromagnetic phenomena

In their reflections, 62 out of 66 students described becoming aware of electromagnetic phenomena in their lived experience as a result of carrying out the contemplative practice.

Students described noticing the relationship between the macroscopic forces analyzed in their classical mechanics courses and fundamental electromagnetic interactions, for instance, the relationship between the normal force between the chair and their bodies, and the frictional force between their feet and the floor, and electrostatic interactions between electrons in the two objects.

Students were often drawn to their personal technologies—including phones, tablets, and laptops—recognizing that these tools depend on complex electrical circuits and energy storage. Others acknowledged that household appliances such as lamps, refrigerators, washers and dryers, and heaters and air conditioning units depend similarly on electrical circuitry. After contemplating the electrical circuits at the foundation of their personal tech-
nologies and appliances, many students extended their awareness further, contemplating electrical grids, power plants, and sources of energy.

Besides personal technologies, light was perhaps the most commonly discussed electromagnetic phenomenon. Students generally began by acknowledging that the human sense of vision relies on the detection of electromagnetic waves by our eyes. They noted the emission of light by electronics, lamps, and the Sun, as well as the scattering of light off objects in their surroundings. Many students extended beyond the visible portion of the electromagnetic spectrum to discuss the use of radio waves for communication, microwave ovens, the transmission of heat via infrared radiation, the health hazards of ultraviolet radiation, and medical imaging using x-rays.

Students also reflected on the presence of electromagnetic phenomena on planetary and astronomical scales. They described the Rayleigh scattering of sunlight to produce the Earth’s blue sky and the colors of the sunset. They discussed electrical storms, planetary magnetic fields, aurorae, and the interaction between electromagnetic waves and planetary atmospheres. They also noted the generation of electromagnetic waves within stars and galaxies as well as the relative importance of gravitational and electromagnetic interactions on cosmological scales.

Following these descriptions, students often came to the realization that electromagnetic phenomena completely pervaded their immediate experience. In one representative passage, a student wrote,

“This contemplative practice helped me think about how little I understand and think about something that affects my life every single day. Without it my day to day life would be unrecognizable and it is hard to think of an aspect of my life that is completely independent of electromagnetism.

Only four students did not mention electromagnetic phenomena in their reflections. Of those four, three discussed the somatic and mental benefits of their experience. The remaining student composed an abstract essay on energy exchange.

3.2 Awareness of interdisciplinary connections

In their reflections, 34 out of 66 students described becoming aware of interdisciplinary applications of electromagnetic principles.

Students expressed significant interest in the ways electrodynamic principles affect human physiology. They noted the subtle but pervasive effects of
electrical forces on their bodies, including the currents governing heartbeats via pacemaker cells, the flow of ions through neurons, and how perception necessitates the conversion of physical phenomena in various forms to electrical signals in the brain. A few displayed even more specific understanding of physiology, recognizing that selective ion channels or action potentials were the results of electromagnetic interactions.

Students also drew connections between electromagnetic theory and their knowledge of chemistry and biochemistry. In particular, many noted the importance of electron flows in both fields,

I thought about how I learned in biochemistry class that almost everything in life can be reduced down and explained as a flow of electrons, meaning that electricity plays a role in every aspect of our lives, not just in electronics and technology.

Students also considered the role played by electrons in forming various types of chemical bonds. One student discussed the neutralization of charge, and how acids and bases act as electron acceptors and donors. Finally, in discussions of electromagnetic radiation, students frequently mentioned the relationship between the energy levels of electrons in atoms and the colors of light emitted by different chemical elements.

3.3 Curiosity

Beyond simply noting the presence of electromagnetic phenomena in their lived experience, 35 out of 66 students experienced an emergent curiosity about their observations, often following up descriptions of the phenomena with thoughtful questions.

Many questions emerged around electrostatics, personal technologies, and appliances. Students asked questions about the shocks they experience from the buildup of electric charge on their bodies and clothing. One student pondered why there are two, and only two, elementary charges, and why they interact with the strength that they do. Students also wanted to understand the mechanisms underlying their personal technologies: there were many questions about telephonic communication, wifi networks, and computer hardware.

Questions also arose around the physical senses, including general questions about how the brain processes physical stimuli, how mechanical waves are converted into what the brain interprets as sound, and how the brain perceives color. Students also expressed interest in the physics underlying
human physiology and medical devices such as EKGs, EEGs, and MRIs. Several students wondered about the effects of electromagnetic fields and radiation on human health.

Extending their curiosity beyond the electromagnetic phenomena they observed, students also contemplated a number of big-picture questions about the fundamental principles of elementary particle physics. For instance, students expressed general curiosity about the properties of elementary particles and the nature of their interactions. Some wondered whether the universe could exist without electromagnetic interactions. One student pondered whether the four fundamental interactions would ever be unified in a single theory, and expressed a desire to learn more about theoretical high energy physics.

Finally, students expressed a sense of intrinsic motivation to attain a deeper understanding of the principles of classical electrodynamics, especially following the realization that the electromagnetic phenomena they observed were generally more complex than the systems analyzed in class. One student wrote,

I also notice with dismay the utter lack of point charges and/or simple two charge electrostatic systems. On the other hand, this makes me both motivated and excited to dive deeper into electromagnetism: to eventually understand with more with more mathematical and physical precision the complex systems that surround me.

3.4 Appreciation

The benefits of the contemplative practice extended beyond a deepened awareness of electromagnetic phenomena. In fact, 53 out of 66 students expressed some form of appreciation for the somatic, affective, and cognitive effects of the practice, using words such as affirming, refreshing, and rewarding to describe their experience.

Students reported that they enjoyed the opportunity to experience a deep sense of embodiment and relaxation. One student described feeling like the practice allowed them to align their mind with their body. Similarly, students mentioned appreciating the effects of the practice on their affective state. They enjoyed a heightened sense of awareness of themselves, their surroundings, and their experience, as well as a feeling of inner peace and balance.
Finally, students experienced a number of effects on their cognitive function, including a sense of clarity and focus. They particularly appreciated the feeling of curiosity that emerged from the practice, as well as the sense of excitement to learn more about the principles of classical electrodynamics:

A contemplative practice would never have occurred to me as part of a physics course . . . After experiencing this practice in meditation and contemplation, however, I now wonder why such exercises are not more commonly encouraged in science courses. By meditating and contemplating my personal connection with electromagnetic phenomena, I found both relaxation and focus, which then allowed me to find a curiosity and interest in physics which I had not previously felt.

As a consequence of these experiences, many students expressed a desire to integrate a contemplative practice into their daily lives.

3.5 Skepticism

In their reflections, 9 out of 66 students described feeling some initial hesitation about the practice. In some cases, this took the form of an initial judgment about the value of a contemplative practice in a physics course. These students described feeling uneasy, apprehensive, and confused about the assignment. In other cases, students experienced difficulty settling down, relaxing, and feeling present, especially in contrast with their typically active and busy lifestyle. One student described feeling a deep sense of discomfort with complete silence. However, these students ultimately expressed an appreciation for the practice. In one typical response, a student said,

When I read the handout for this assignment, I was very confused. The concept of meditation for a physics class seemed quite strange and foreign. However, . . . I really enjoyed this assignment. Now I am much more mindful of electromagnetic phenomena in daily life, and I think I am going to start meditating regularly.

Only one student questioned whether the meditative element of the practice contributed to a deepened awareness of electromagnetic phenomena.
3.6 Summary

| Theme                           | Occurrence ($N = 66$) |
|--------------------------------|-----------------------|
| Awareness of electromagnetic phenomena | 62                    |
| Awareness of interdisciplinary connections | 34                    |
| Curiosity                       | 35                    |
| Appreciation                    | 53                    |
| Skepticism                      | 9                     |

4 Discussion

In this work, we show that a somatic meditation and contemplation successfully draws students’ attention to a variety of electromagnetic phenomena in their surroundings, allowing them to deepen their awareness of the relevance of classical electrodynamics to their lived experience. The students’ discovery of electromagnetic phenomena closely followed the progression of the guided meditation: as students’ awareness entered their bodies and the space around them, they noted the applicability of electromagnetic theory to their physical senses, the physiology of the human body, the technologies that permeate their everyday lives, and the physical universe on the largest scale. Studies in educational psychology have shown that pedagogical interventions designed to encourage students to discover the personal relevance of what they are learning within their classroom increased both their interest in the material and their performance in the class [35, 36]. Similarly, we find that the contemplative practice naturally evoked students’ curiosity about the role of electrodynamic principles in governing the physical universe, leading to a deep intrinsic motivation to learn.

When contemplating manifestations of electromagnetic phenomena in their experience, students expressed particular interest in the human body and physiology, including perceptions, the nervous system, and the cardiovascular system. Research has shown that students generally perceive physics to be detached from their studies in chemistry and biology, resulting in a fragmented view in which physics does not contribute to their understanding of chemical and biological systems [37]. By failing to explore interdisciplinary connections between STEM fields, traditional physics curricula therefore miss an opportunity both to build disciplinary coherence and to motivate students majoring in other physical sciences or the life
sciences, who constitute the overwhelming majority of students in introductory physics courses [1]. By drawing students’ awareness into their bodies, our contemplative practice offers an opportunity for students to naturally and meaningfully relate electrodynamic principles to chemical and biological systems.

Finally, the contemplative practice had a notably positive impact on the students’ somatic, affective, and cognitive states. Empirical research has shown that contemplative practices, particularly those incorporating elements of traditional mindfulness meditation, can help support student mental health under academic stress by fostering important cognitive processes such as attention and information processing, as well as by decreasing stress and anxiety [38]. Although these effects would not persist following a single meditation session, the contemplative practice may serve to introduce students to the benefits of integrating a mindfulness meditation practice into their daily lives.

Although we were unable to follow up with the students at the end of the quarter, many students mentioned the contemplative practice specifically in their course evaluations as a particularly impactful element of the course. In the future, we would like to administer the CLASS as a pre- and post-test in order to obtain quantitative data on the effect of contemplative practices on students’ beliefs about physics, as well as to compare contemplative practices with other interventions aimed at integrating formal theory and personal experience in the undergraduate physics curriculum.

In an era in which students leave our undergraduate courses unconvinced of the applicability of formal physical principles to the real world, contemplative practices offer an opportunity for students to attend to manifestations of physical phenomena in their lived experience. This process naturally allows them to draw connections between the abstract and the experiential, but, more importantly, to be motivated by a genuine sense of wonder about nature. The German natural philosopher Johann Wolfgang von Goethe described this process beautifully when he wrote,

The desire for knowledge first stirs in us when we become aware of significant phenomena which require our attention. To sustain this interest we must deepen our involvement in the objects of our attention and gradually become better acquainted with them. Only then will we notice all manner of things crowding in upon us. We will be compelled to distinguish, differentiate and resynthesize, a process which finally leads to an order we can survey with some degree of satisfaction [39].
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Appendix: Contemplative practice guidelines

Introduction

The objective of this contemplative practice is for you to explore your personal experience with electromagnetic phenomena in your everyday life. There is no one right way to do this practice, and no one right way to reflect on it. Simply pay attention to your experience and be as open as you wish in your reflection.

Getting ready

Find a place on campus in which you can sit, relatively undisturbed, for about thirty minutes. It may be your dorm room, the library, an empty classroom, a study lounge, or another reasonably quiet space. Set your phone on silent and put aside any other potential distractions.

Meditation

1. Start by stretching out your arms and legs, wiggling your fingers and toes, and loosening up and relaxing your whole body. Then, find a comfortable and upright seated position (on a chair is great) and simply become aware of your body. Sense its position, weight, and inner space.

2. After a while, bring your attention to your seat, where your body is supported by the chair. Feel the weight of your whole body and how it is drawn to the Earth. Let your body really settle and be at ease. Appreciate the simplicity of being bodily present, here and now.

3. Now, bring your attention to your head. Close your eyes or lower your gaze. Concentrate on your sense of hearing. Be open and sensitive to any sounds from the environment, especially the background noises that we usually don’t notice. You can note sounds with a simple mental label—*bird singing, traffic noise, refrigerator hum*—but try not to enter into a discursive thought process. At the same time, try to notice the larger quality of silence that surrounds whatever you hear from moment to moment. Sense the whole space around you, extending beyond the walls and what you can see from where you sit. Experience the vast quality of your awareness.

Based on the Grounded/Aware/Present (GAP) practice in D. I. Rome, *Your Body Knows the Answer* (Shambhala Publications, 2014).
4. Finally, bring your attention into the center of your chest, placing your hand gently over your heart and experiencing the quality of your presence. You are simply here, alive, breathing, feeling, experiencing your basic existence. It is happening right now, at this very moment.

5. Let your attention encompass your whole body. Then, gently open your eyes, raise your gaze, and extend your awareness into the space around you.

**Contemplation**

Maintaining your awareness of your body and the space around you, contemplate the manifestations of electromagnetic phenomena in your surroundings. Some may be apparent, some may be less so. Questions, confusions, distractions, and insights may arise. Make room for all of it. Whatever your unique experience may be, it is relevant and valuable.

**Reflection**

Please write up a reflection on your experience with this practice. Your reflection should be between one and two single-spaced pages in length.