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Supporting Aesthetic Experience of Science in Everyday Life

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ABSTRACT
Researchers have argued that a central goal of science education is to transform students' out-of-school experiences, so that students have aesthetic experiences of the world that would not otherwise be available to them. The goal of this paper is to articulate a set of design principles that support this goal. In doing so, I will first position this as a problem of transfer, and describe a perspective on transfer in which an idea or experience is not so much abstracted from its original context and applied to a new context, but one in which the learning context incorporates out-of-class contexts, and vice versa. After characterising a range of context domains that may be positioned intercontextually, I will argue that such transfer of scientific activity is fostered in classrooms that are themselves intercontextual: where out-of-class contexts are invoked by students in scientifically consequential and aesthetically meaningful ways as they develop and vet ideas. I develop a taxonomy of intercontextuality, building on existing taxonomies of transfer, and describe classroom episodes of such intercontextuality from an undergraduate course that shows evidence of high transfer of aesthetic experience. I then offer suggestions for how elements of course design (e.g., disruptions to typical resources, and shifting power to students) may support students in such aesthetic experiences.

KEYWORDS
Aesthetic experience; intercontextuality; transfer

1. Introduction

1.1. *Aesthetics in science education: approaches and challenges*

As this issue reflects, there is growing attention to the importance of aesthetics and related constructs in science education. The nature of the aesthetic experience and its role in science classrooms varies: some attend to students' affective judgments to understand how these may initiate and sustain scientific inquiry (Radoff, Jaber, & Hammer, 2019) - for example, the "angst required to motivate the search" (Root-Bernstein, 2002, p. 77); others highlight the role of the aesthetic experience to more broadly engage students in making meaning and agency (Caiman & Jakobson, 2019); and then there are those suggesting the aesthetic experience of science is more than *entangled* with science learning, it is a defining feature of disciplinary work and should be a central goal of science instruction (Fischer, 2013; Girod & Wong, 2002; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010; Wickman, 2006). These com-

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plementary strands of research all call attention to the importance of the integration of affective judgments, conceptual understanding, and practical engagement in science through explicit attention to aesthetic experience.

For this paper, I approach aesthetic experience as articulated in the work by Girod and Wong (2002), who argued that the nature of science learning may be productively framed not as conceptual change (e.g. Posner, Strike, Hewson, & Gertzog, 1982) or engagement in scientific discourse (e.g. Lemke, 1990), but instead as an increased capacity for aesthetic experiences in the world. That is, science education should foster not only rich disciplinary knowledge, but "a deep appreciation for the beauty and power of [science] that transform one's perceptions of the world and of her/himself as knower" (Girod & Wong, 2002, p. 199). This work is operationalised by Pugh et al. (2010) in the Transformative Experiences survey, and parallels the work of Wickman (2006), who has highlighted the inseparability of science from aesthetics, and (Östman & Wickman, 2014, p. 378), who note, learning is 'not about the transformation of an individual's cognitive structure, but rather. . . the transformation of observable habits in action.' Such a focus shifts our attention from students' understanding of content and participation in scientific practices to a focus on how their learning supports an integrated engagement with and activity in the world, including the perceptual, emotional, intellectual and practical elements of that engagement. Moreover, the attention to aesthetic experience is not meaningful for its connection to conceptual understanding, but the reverse: the motivation for conceptual understanding is its ability to engender meaningful experiences of the world. This focus explicitly draws our attention outside the school and workplace. Such a focus aligns with perspectives on Dewey's (1938/1998) approach, is consistent with the descriptions of practicing scientists (e.g. Chandrasekhar, 2013; Root-Bernstein, 1989, 2002), and offers a richer perspective on the goals of curriculum and instruction, including, as Girod and Wong (2002, p. 207) note, 'more individuality of experience, often spawning creative leaps and more divergent thought.' Students are not positioned as joining established communities, but transforming their communities through their own insights and ways of seeing the world.

Under this framing, however, meeting the goals of science education can seem all the more challenging. The latest science standards in the United States, which largely determine professional development programs and curriculum choices, outline what students should know and do in classrooms (NGSS Lead States, 2013), not how they should feel about ideas or experience the world outside of class. Those goals are often considered outside the scope of education in general and science education in particular. Though such a divide has been met with challenges (e.g. Root-Bernstein, 1989), as Wickman 2006 notes in his book on aesthetic experiences of science, scientific writing has become only more objective in its rhetoric (Gross, Harmon, Reidy, & Reidy, 2002); the divide is not narrowing. Moreover, when we construe aesthetic experience as a form of transfer, that students use ideas and experiences from class to bring new meanings outside of the instructional context, we note that goals related to transfer are unlikely to be met (e.g., Barnett & Ceci, 2002). This is true for modest goals of transfer between academic contexts, to say nothing of the ambitious goals of aesthetic experience, e.g., a student spontaneously using ideas from physics to enrich her out-of-school life as a bartender.

1.2. Research questions and summary

In the current research, I draw on students' self-reports of aesthetic experiences outside of the classroom to address the following questions:

(1) What aspects of *classroom activity* are transferred to and enacted in *out-of-class* aesthetic experiences?
(2) What aspects of the instructional context supports such transfer?

To do so, I draw on work by Pugh et al. (2010) that operationalises aesthetic experience via a survey to identify a course that supports meaningful aesthetic experiences of science outside of the classroom (Girod & Wong, 2002). This course (taught by the author) was not explicitly designed to support aesthetic experience. Lacking the recommendations that other researchers make (Girod, Rau, & Schepige, 2003; Pugh, 2002; Pugh & Girod, 2007), for example, explicit attention to '(a) crafting ordinary science content into important and powerful ways of seeing the world; (b) modeling the power of these science ideas to transform our lives, and (c) scaffolding students' efforts to live differently because of these new ideas' (Pugh & Girod, 2007, p. 20), we can ask why this course succeeds when other introductory physics courses fail.

Ultimately, I will argue that, for this course that supports rich aesthetic experiences in everyday life, these experiences are not so much abstracted from the classroom context and replicated in 'everyday' contexts, but that the learning context deeply engages with everyday contexts so that it includes them, in what I will refer to as intercontextuality (Engle, Nguyen, & Mendelson, 2011); this draws from work on intersubjectivity (Rommetveit, 1976) and intertextuality (Bazerman, 2004). After characterising a range of context domains that may be positioned intercontextually, I will argue that the enactment of scientific aesthetic experiences in out-of-class contexts are fostered in classrooms that are intercontextual: where out-of-class contexts are invoked by students in scientifically consequential ways as they develop and vet ideas. I describe classroom episodes of such intercontextuality and suggest design principles for such classrooms.

Below I begin with a brief description of the survey and its results, and the course context in which we situate this research.

2. The course, survey and results

2.1. Transformative experiences survey

Drawing on Dewey's work on art and aesthetics, Girod and Wong (2002); Pugh (2002) approach aesthetics in science through the lens of the aeasthetic *experience*. An event 'that has its own completeness, is easily remembered, and is readily differentiated from other events and experiences' ... Such experience 'involves a build-up and resolution of anticipation... [and] it brings about a transformation of one's relationship with the world' (Pugh & Girod, 2007, p. 11). Seeking to operationalise the construct to study the prevalence of transformative experiences in science classrooms, Pugh et al. (2010) developed a survey addressing whether or not students notice ('expansion of perception'), value ('experiential value') and use ('motivated use') ideas from science in their everyday lives, on a continuum from in class to out-of-class contexts.

As part of a broader study on transformative experiences in introductory physics, this Transformative Experiences survey was administered to a range of undergraduate introductory physics classes, including traditional courses for science and engineering majors, and inquiry-oriented courses for preservice elementary teachers. There was a section added to the original survey for students to add comments.

2.2. TE survey results in two courses

When told the premise of this survey, undergraduate students in a traditional introductory physics course for science and engineering majors laughed - in every section across two universities. In one section a student joked with his lab group, saying,'yeah, the air drag caused by me riding my bicycle causes my beard hairs to deflect 13 degrees towards my neck.' And in response to a question asking whether or not students think of concepts from class when they see everyday objects, such as eyeglasses and television screens, only one of the 55 students surveyed 'strongly agreed;' nine 'agreed.' The other 45 students, then, report that classroom instruction on optics has not influenced how they experience everyday objects that employ these principles.

In contrast, when students in an undergraduate science course for elementary education majors, Scientific Inquiry (Atkins & Salter, 2015; Atkins Elliott, Jaxon, & Salter, 2016), were given the survey, not one student strongly disagreed. 13 of 25 strongly agreed with that statement, 9 more 'agreed.' One student, Maddy, offered the following example:

> Right now, our group is working on the idea of how glasses and contacts change the shape of your cornea to balance out a person's misshapen cornea. We thought we could explain it by explaining that people with near sighted vision need glasses with thicker glass on the sides and that people with far sighted vision need glasses with thicker glass in the center. However, we only knew what near sighted glasses looked like. We didn't know what far sighted glasses (ex. reading glasses) looked like. When I was at Walgreens [a pharmacy] the other day, I saw some reading glasses and decided to investigate. And sure enough, the glasses were thicker in the center and as the intensity of the prescription increased, so did the thickness of the center. I was so proud of our group to turn out correct!

Students' quantitative and qualitative responses across the set of survey questions indicate that students in the Scientific Inquiry course have significantly different out-of-class experiences related to the content of the course than those in the traditional physics course Frank and Atkins (2013).

2.3. Overview of the paper

After describing the course, I begin with an analysis of Maddy's experience at Walgreens, first identifying how this is consistent with prior descriptions of aesthetic experiences of science. I then employ a taxonomy of transfer from Barnett and Ceci (2002) to characterise her activity, and use this characterisation to motivate the notion of intercontextuality. Using data from video tape, field notes, and students' written assignments over four semesters of instruction, I describe classroom episodes rich with intercontextuality by adapting the Barnett and Ceci (2002) taxonomy of transfer. In particular, it is not simply that non-scientific contexts are invoked in the classroom, but those contexts are invoked in ways that are scientifically consequential: those contexts have bearing on the development and vetting of students' scientific ideas (cf., Ma, 2016). Finally, I suggest that the Scientific Inquiry course supports rich aesthetic experiences of science out of class because the course is continuous with out-of-class contexts; I attribute this largely to a course design that removes traditional instructional 'scaffolds' or support, requiring students' own ideas, experiences and materials be brought to bear in class. In this way, the aesthetic experience of science in out-of-class contexts - the ability to participate and delight in the world as a physicist might - is supported by the richly intercontextual ways in which that knowledge was constructed (e.g., Jornet, Roth, & Krange, 2016; Wagner, 2006) and positioned (Greeno, 2006) in class.

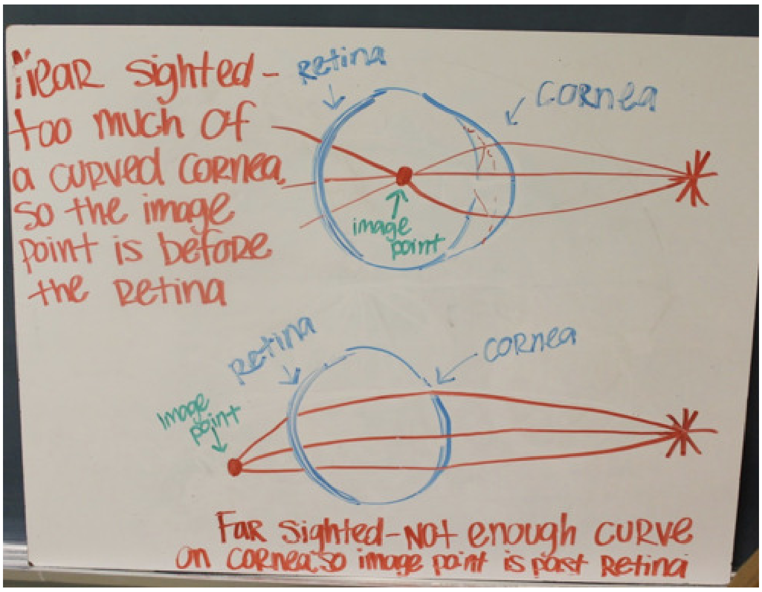
2.4. The class and research context

The course presented here is one for preservice teachers, and was designed to meet the Inquiry standards from the United States' National Science Education Standards (National Research Council, 1996). Though more recent standards (NGSS Lead States, 2013) explicitly integrate the practices of inquiry with disciplinary core ideas, this document put inquiry and its attendant practices on equal footing with traditional science content. While this structure had drawbacks, it afforded the opportunity to teach an undergraduate course that de-emphasised 'right ideas' as learning outcomes to focus on inquiry-oriented outcomes. That is, although the focus in the course was developing coherent, mechanistic models of phenomena, students were assessed on how they developed and vetted ideas as a class, and not the canonical correctness of the ideas themselves. The course, then, has no textbook or lab manual, but a range of simple materials, an initial question, and extended weeks of inquiry. The course is more fully described in Atkins and Salter (2015); Atkins Elliott et al. (2016).

For each iteration of the course, we have videotaped each course session, usually with two cameras, one capturing the entire class and one following a particular group. In addition, an undergraduate researcher (who videotapes the course) maintains daily field notes, indexed to the video, to aid in finding particular instances of the course. The instructor (who is the author) also summarises the day's activity in her own field notes, usually with a snippet from the video or images from class. All student homework is photographed, as are student notebooks; in-class artifacts (whiteboards, experimental set-ups, etc.) are captured to the degree it is possible. Over 4 semesters we also collected TE survey data from the class.

In the quote introduced above, Maddy is in a class of 24 undergraduate preservice elementary education students who have been studying light and vision over eight weeks of instruction. After developing models to explain images visible in pinhole cameras, the class has recently dissected cows' eyes, and lab groups of four have been constructing models of how light interacts with the eye to create an image on the retina. Maddy's group has proposed an explanation for near- and far-sightedness, and they have recognised that their model has implications for how lenses can fix these problems. Her group's whiteboard is shown in Figure 1.

A week after constructing the above whiteboard, students are given an adapted Transformative Experiences survey (Frank & Atkins, 2013; Pugh et al., 2010). The survey is given online, with free-response boxes for students to provide examples. One question on the TE survey asks 'Sometimes when I'm looking at a tv screen, a camera, glasses or everyday objects, then I think about it in terms of our rules for light rays.' Maddy 'agrees strongly' with this statement and gives the anecdote quoted above.



(a) A slightly shorter sub-caption.

Figure 1. Maddy's group's whiteboard describing their model of far- and near-sightedness, which inspires their study of eyeglasses.

3. A definition of aesthetic experience as applied to Maddy

3.1. Defining aesthetic experience

For the purposes of this research, I employ definitions of aesthetic experience in science as articulated by Girod et al. (2003), with roots in Dewey (1934/2008), and operationalised by Pugh et al. (2010). In particular, I use the definition of aesthetic experiences in science as **transformative**: scientific ideas "literally [transform] who we are and how we see the world," **unifying**: not only in the unification of "the practical, emotional and intellectual from one another," but also that the experience 'add[s] coherence to our understanding of the world;' and **compelling and dramatic**: the experiences of science are 'saturated with emotion,' and it is 'common for these students to think about science ideas outside class, to search for examples and illustrations of ideas, and to tell others about what they've learned, relishing in the excitement and engagement of looking at the world with wider eyes' (Girod et al., 2003, p. 578).

3.2. 'Walgreens' as aesthetic experience

In Maddy's example, these characteristics are clearly present. The activity in class has been **transformative**: she is not simply a shopper, but transformed into a scientist in Walgreens, repurposing the eyeglasses to meet her research group's epistemic goals, and she sees glasses not simply as object but part of a scientific activity. The activity is **unifying**: this is not a detached collection of data, but the practical - the activity - is linked to both the anticipatory, the "angst required to motivate the search" (Root-Bernstein, 2002, p. 77), and its resolution - her sense of pride in the confirmation; in addition, it represents a unification of ideas: the ideas from class about how the lens of the eye works is consistent with the shape of eyeglasses at Walgreens. And finally, this is a **compelling and dramatic** story, 'saturated with emotion,' in which Maddy

Table 1. Contexts for transfer from a meta-analysis by Barnett & Ceci (2002).

	Near				**Far**
Knowledge	Mouse v. rat	Biology v. botany	Biology v. economics	Science v. history	Science v. art
Physical	Same room at school	Different room at school	School v. research lab	School v. home	School v. the beach
Temporal	Same session	Next day	Weeks later	Months later	Years later
Functional	Both clearly academic	Both academic but one nonevaluative	Academic v. filling in tax forms	Academic v. informal questionnaire	Academic v. at play
Social	Both individual	Individual v. pair	Individual v. small group	Individual v. large group	Individual v. society
Modality	Both written, same format	Both written, multiple choice v. essay	Book learning v. oral exam	Lecture v. wine tasting	Lecture v. wood carving

is emotionally invested - proud of her group - as she is attending to features of the lenses, and repeating the story here on a survey.

How do we account for the quantitative differences in student responses, and the qualitative differences in the engineering student's imagined 'beard angle' experience and Maddy's aesthetic experience? Barnett and Ceci (2002), seeking to account for disparities in research on teaching for transfer, offer a taxonomy which considers six separate forms of context across which transfer could happen: knowledge domain, physical context, temporal context, functional context, social context and modality.

4. A taxonomy of transfer as applied to Walgreens

4.1. Contexts of transfer

Barnett and Ceci (2002) identify six context domains that influence the likelihood of transfer (quoted in Table 1), noting that the more similar the contexts of learning and transfer, the more likely transfer is. Each is summarised in turn below, as I describe how these taxonomies play out in Maddy's example.

4.1.1. Knowledge domain

The knowledge domain dimension identifies to what degree the transfer scenario is within or across knowledge domains. 'Physics to chemistry might be considered nearer transfer than physics to English, as more elements would presumably be shared' (Barnett & Ceci, 2002, p.263). Maddy is not taking her knowledge of how light rays bend and using this to consider how other rays might bend; instead, the transfer in 'knowledge domains' is minimal: an idea she had been using in class to understand glasses is used in Walgreens. I argue that, using the Barnett and Ceci taxonomy, there is no transfer across knowledge domains in this example.

4.1.2. Physical context

The physical context dimension includes 'both macroaspects, such as whether the training and transfer phases are conducted at school, in a research lab, in the home environment, and so on, and microaspects, such as whether the exact same room is used and whether the experimenter is the same' (Barnett & Ceci, 2002, p.263). At the macroscopic level, Maddy's activity seems like far transfer: ideas constructed and used in the classroom are being used in a drugstore.

At a micro level, the settings are again different with one notable exception: eyeglasses. The relevant physical object in class for Maddy's group's activity was far-sighted glasses and her lab group hoped to find near-sighted glasses, which are present in Walgreens, suggesting a much more 'near' transfer than would otherwise be the case. Of course, in any classroom there are likely to be eyeglasses present, and this does not inspire classroom activity in the drugstore. And so it is not the presence of eyeglasses in both settings, but the way Maddy has positioned glasses in both settings that allows for the physical context to encompass both classroom and drugstore. Because of classroom activity, she is able to perceive an affordance of these reading glasses that she would not have been able to perceive otherwise (Greeno, Smith, & Moore, 1993).

The similarity, then, of two physical contexts is not objective, but determined by participants in those contexts, subject to their histories. As Erickson and Schultz argue, 'Contexts are not simply given in the physical setting… Rather, contexts are constituted by what people are doing and where and when [and with whom] they are doing it' (Erickson & Schultz, 1997, p. 5). For Maddy, her activity in class, and continued into Walgreens, constructed the contexts and their similarity.

4.1.3. Temporal context

Maddy's trip to Walgreens was the same week, if not the same day, as her in-class investigations. Temporally this is 'farther' transfer than many psychological studies, but relatively 'near' nonetheless. I argue, however, that it matters little if this occurs at, say, 7 pm and not a temporally 'closer' noon. The activity at Walgreens is in response to Maddy's in-class investigations, while also anticipating a return to class, so that there is an unfolding narrative linking prior classroom activity with this out-of-class context, and, we can imagine, this out-of-class activity anticipates future transactions, as she reports to her group of their successful prediction. As Jornet et al. (2016) note:

> Whatever [a] turn is doing in [a] situation is determined not by the turn in itself (self-action) but by its relation to the whole social action that is being accomplished… a next turn displays how the prior turn becomes relevant and consequential for the unfolding episode of transaction. (p. 307)

This touches on Dewey (1934/2008) discussion of what it means to have 'an' experience: in ordinary experience,

> We put our hands to the plow and turn back; we start and then we stop, not because the experience has reached the end for the sake of which it was initiated but because of extraneous interruptions. . . In contrast with such experience, we have an experience when the material experienced runs its course to fulfillment. . . [The experience] is so rounded out that its close is a consummation and not a cessation (p. 35).

Maddy's experience in Walgreens, then, is part of a broader social action, beginning with ideas and anticipation in class. There was a cessation of activities in class ('not because the experience has reached the end for the sake of which it was initiated but because of extraneous interruptions'), which led to a consummation of activity outside of class, which then suggests further activity in class. The iterative nature of the development of ideas in this course, where models are proposed, tested, critiqued, and refined over time promotes ongoing activity (and temporal 'nearness') like the one described here.

4.1.4. Functional context

Functional context is described as 'conceptually related to the notion of functional fixedness (Duncker, 1945), in which the use of tools is tied to their original purpose' (Barnett & Ceci, 2002, p.263). Transfer, they argue, is less likely when the object or materials in a learning context must be applied to a novel purpose in the transfer setting.

The function of a drugstore and the function of a classroom are, of course, not terribly related. At a more detailed level, if we consider the function of glasses, these are rarely positioned as evidence for scientific claims: the use of reading glasses to address scientific claims is, in some ways, a far transfer of functional context. However, this breach of functional fixedness occurred earlier: it was during class time that Maddy's lab group began investigating eye glasses to support their scientific claims. Her use of the glasses at Walgreens simply extends that investigation.

4.1.5. Social context

Barnett and Ceci (2002, p.263) note a 'skill acquired in a group setting might not be equally well applied when alone or vice versa.' Maddy was working in an assigned lab group of four students; at Walgreens, she is most likely alone, and positioned not as a student but as a customer. Again, one could describe this as a far transfer across social contexts. However, she is invoking her peers while there, drawing on their ideas and imagining them as an audience for her investigations; she notes that she thinks of her group: 'I was so proud of our group to turn out correct!' A consideration of the social context of learning and of transfer should, then, call our attention not to the physical presence or absence of a group during learning and during transfer, as this taxonomy might suggest, but the ways in which the individual engaging in learning and transfer does or does not access and make relevant the same social groups to which they belong in both contexts.

4.1.6. Modality

The final dimension of context that Barnett & Ceci consider is that of modality: did learning happen in one modality (reading, say), and transfer in another (woodworking)? The Scientific Inquiry classroom is richly multimodal: students are using the whiteboard, their lab notebooks, conversations within and between lab groups, and a set of materials, including their own eyeglasses. Few of these resources are available at Walgreens. Nonetheless, her investigation is continuous with the activity from class: the examination of the curvature of eyeglasses to confirm a prediction, suggesting that the modes of investigation are the same across these two different contexts.

Table 2. Contexts for transfer in Maddy's example.

Context	Cognitivist	Situative
Knowledge	Optics and optics. (Near transfer.)	Optics and optics. (Near transfer.)
Physical	Science class on campus to a drug store off campus. (Far transfer.)	Near-sighted glasses to far-sighted glasses. (Near transfer.)
Temporal	Days later. (Relatively far transfer.)	Beginning of investigation and end of investigation. (Near transfer.)
Functional	Academic context to a shopping trip context. (Far transfer.)	Both contexts are academic: pursuing and verifying models. (Near transfer.)
Social	Performed in a group, performed alone. (Far transfer.)	Performed in a group and performed imagining the group as audience. (Near transfer.)
Modality	Multimodal (whiteboards, notebooks, spoken, and with materials) to a single (materials). (Far transfer.)	Examining shape of glasses; examining shape of glasses. (Near transfer)

4.2. Discussion

To summarise, a traditional (or cognitivist) view of transfer and context suggests that Maddy's activity constitutes far transfer, while a more situative or transactional view (*e.g.*, Jornet et al., 2016) suggests that this is more 'near' transfer (see Table 2).

Maddy's experience at Walgreens – an aesthetic experience that is transformative, unifying and compelling – is best described not as transfer of a particular activity or element of knowledge from the classroom to a 'far' context at all, but as a moment of rich intercontextuality, where contexts of classroom activity (including knowledge, physical, temporal, functional and social contexts) are invoked in the context of a shopping trip in a continuation of classroom activity. Furthermore, this intercontextuality was seeded in the classroom, as her group began vetting their ideas with their own glasses, positioning these everyday objects as a central element in their science investigations; by leaving questions unanswered and future experiments anticipated; as they debated and argued with one another - bringing elements of their out-of-class lives to bear on our scientific ideas; and with rich multimodality, as they used sketches, whiteboards, lenses, glasses and conversations to develop their models of light.

This leads to the following assertion: **instructional contexts that are intercontextual in scientifically consequential ways are ones that promote 'transfer' of scientific activity to out-of-class contexts**. It is this assertion that frames the following sections of the paper, and prompts the following questions: (1) above, we explored an out-of-class aesthetic experience of science and I argued that this is not far transfer to a new context, but the continuation of class activity that made the 'new' context continuous with the classroom. Is there evidence of rich, scientifically consequential intercontextuality within the classroom context as well? and (2) what design principles support such intercontextuality in class? These are addressed in turn below.

In doing so, we turn away from an explicit attention to aesthetic experience; we will return to the question of intercontextuality and aesthetic experience in the conclusion of these sections, noting that the holistic nature of aesthetic experience in science all but demands such intercontextuality of experiences in science education.

5. A taxonomy of intercontextuality & class examples

5.1. Methods

My goal in the following sections is to articulate a taxonomy to describe intercontextual classroom activity in Barnett & Ceci's (2002) six transfer domains. My expectation is that these intercontextual moments are a critical way in which activity in the course facilitates the bridging of classroom experiences to out-of-class contexts, supporting aesethetic experiences in everyday life.

For each, the domains of IC were articulated through a progressive refinement of hypotheses (Engle, Conant, & Greeno, 2000). Beginning with Barnett and Ceci (2002)'s definitions of six context domains, I generated tentative hypotheses for how these may be modified to capture intercontextuality in scientific inquiry. For each domain, I then reviewed past field notes, video and student artifacts to find examples of such intercontextuality, generating multiple examples for each domain. For each domain, these examples were compared to one another and the proposed definition. These cases were then used to refine the definitions for intercontextuality domains, or to reject the exemplars. Below are the outcomes of this refinement: definitions of intercontextuality for each domain of context, with select exemplars from the corpus of data. These exemplars serve to both illustrate particular forms of intercontextuality, and present evidence of its presence in the course with high aesthetic experiences out of class.

5.2. Domains of intercontextuality

5.2.1. Knowledge domain intercontextuality

Knowledge domain IC asks: are our ideas in class accountable to and informed by other domains of knowledge? For example, the class was modeling reflection, and, unlike the other students, Steven shares a model that has the mirror as absorbing a great deal of light; he explains this model using a common experience of metal playground slides getting hot in the sun, together with his knowledge about energy not being created or destroyed.

In another instance, students are puzzling over how three colors are sufficient to produce the full gamut of color vision. Mary, a student who is also a bartender, uses her knowledge of drink recipes — that three ingredients can be used in varying ratios to produce a vast number of different mixed drinks — to argue that this is plausible. Her knowledge (mixing recipes for drinks) from a domain (bartending) is being positioned in our science course as consequential to determining the plausibility of our ideas.

5.2.2. Physical intercontextuality

Physical intercontextuality addresses the following questions: Are the objects used in class particular to the classroom and lab environment, or are students invoking 'outside' objects and spaces to inform our developing ideas?

Consider the examples introduced above. Objects (a slide and mixed drinks) and places (a playground and a bar) that are not physically present in the classroom are positioned by students as relevant to the construction and vetting of scientific ideas. Consider, too, objects that students employ: Alanna uses her spoon to experiment with reflection from curved surfaces - comparing this to the curved parabolic mirror in our flashlights; Maddy's group uses eyeglasses to test a model of near-sightedness.

While the spoon and the glasses are usually in a classroom, they are not rarely a consequential part of a typical classroom context. As Gee (2005) notes,

> [Contexts] do not just exist... they are actively created, sustained, negotiated, resisted, and transformed moment-by-moment through ongoing work... Out in the world exist materials out of which we continually make and remake our social worlds. The social arises when we humans relate (organise, coordinate) these materials together in a way that is recognisable to others. (p. 191)

It is the work that students do that transforms spoons and eyeglasses into lab equipment, recognisable to others as consequential to our scientific activities and a meaningful part of the academic context.

5.2.3. Temporal intercontextuality

In *consequential* temporal intercontextuality, ideas are positioned as accountable to — even vulnerable to — future ideas and information. In this course, the construction of ideas is iterative: we develop, challenge, critique, modify and, at times, abandon ideas over a semester of instruction. We do not finish the day's lab and, in the next class session, turn our attentions to new ideas. Nor do we merely use those ideas, treating them as settled. Instead there is an evolving narrative - one that is both forward- and backward-looking. This builds on Engle, Lam, Meyer, and Nix (2012, p. 218), who argue 'transfer is encouraged to the extent that a learning context and therefore the content learned within it ... can be recognised as providing resources for productive action in potential future transfer contexts.' That 'productive action' is not simply the use of classroom ideas, but the assessment of ideas, where the ideas are continually held accountable to other contexts.

Examples of this intercontextuality include our case from Walgreens, as Maddy confirms a prediction we could not confirm in class. In another instance, Wendi is dissatisfied with our class model of primary colors (in particular, that magenta, and not red, is a primary color for paints), and suspects that our low-quality paints may be the cause. One weekend she uses her set of oil paints at home to examine the ideas, which she then brings to class as a way of disputing our previously established claims. In this way, the ideas from class are not simply transferred across time, but, instead, activities that occur later may speak to and modify ideas, in a continuation of ongoing classroom activity.

5.2.4. Functional intercontextuality

This form of IC considers whether physical and conceptual objects serve functions than are atypical, a break in 'functional fixedness' (Duncker, 1945). As noted above, Alanna uses a spoon from her backpack (which she used to eat breakfast in our early morning class) to examine why images are upside down in curved mirrors. In doing so, she has positioned a spoon as lab equipment and the spoon is functionally intercontextual in this moment: its purposes and the 'mind-set' (Barnett & Ceci, 2002) that is evoked in the user have shifted, so that a utensil is now of consequence to our scientific ideas.

This is similar to physical intercontexuality noted above, where non-scientific objects - like glasses - are used in science class. However, it is not just that the spoon is used as lab equipment; using a measuring cup if a graduated cylinder cannot be found would only weakly shift its function; using a spoon as a curved mirror is a much greater break in intended function.

5.2.5. Social intercontextuality

While our social identities are always an element of our personas, this domain asks if these social groups students belong to are positioned as relevant to our inquiry. Above, we have a student's identity as a bartender as relevant, in addition to Wendi's identity as an artist. Another example comes from a conversation during a unit on sound, in which a student asked if sound only seems to travel 'through' a wall, but is actually created by the wall's vibration. In response, a student who has served in the military describes the feeling of a blast traveling through you, describing seeing the grass ripple as the sound wave advances and you feel it pass through, saying: 'sure, you hear it, but you feel it, too.' In each of these cases, the students position themselves as having a particular identity - a bartender, an artist, a soldier - with the unique knowledge from those positions that, rather than being barriers to participation in scientific inquiry, are consequential to our developing models.

5.2.6. Modal intercontextuality (multimodal)

'Modal' intercontextuality is multimodality. In particular, we are interested in moments when students employ modalities that are more typically employed in non-scientific contexts. Scientific representations are richly multimodal, and yet frequently constrained to very specific forms: graphs, diagrams, lab reports and problem sets. There are examples of students using atypical modalities: rapping physics (Emdin, Adjapong, & Levy, 2016), inventing a 'bone song' (Barton, Tan, & Rivet, 2008) or the AAAS 'Dance Your PhD' (Bohannon, 2008); however, these are rarely consequential to the development of a scientific idea. Examples of *consequential* multimodality in this course, in which modalities that are not associated with science are brought to bear on our ideas, are briefly described below.

In developing a model of reflected light, students from one group describe light rays as 'shattering' upon reflection and reflecting off in all directions. Alyssa refutes this idea, noting that such a representation is like a 'cartoon lightbulb.' That is, when an artist wants to represent 'glowing,' they draw lines emanating off the object, like a sun's rays or lightbulb's glow and, as Alyssa notes, 'this desk is not glowing.' As students debate this, one describes reflection from a mirror as being a 'ptew-ptew' kind of sound, and reflection from paper as a vibrato 'aaaah.' Another notes that objects under a spotlight seem to glow, which prompts yet another student to describe watching tapes of dance performances, and noting that there is, in fact, a fuzzy glow around the dancer. This is then related back to the moon appearing to glow, and students then decide that, in fact, the only reason a desk does not appear to glow is because the room is not darker than the desk. In this conversation, then, cartoon representations and tapes of dance performances were consequential to developing this idea that explains, in part, why object that emanate light appear to glow while other objects that reflect light in all directions don't.

We summarise these 6 contexts in Table 3.

5.3. Intercontextuality as aesthetic experience

Above, I have adapted the taxonomy of transfer from Barnett & Ceci to construct a taxonomy of intercontextuality that may be present in science classrooms (summarised in Table 3). However, the examples that are used to refine and illustrate these categories were not selected as examples of aesthetic experience in class. Nonetheless, there

Table 3. Intercontextuality in the Scientific Inquiry course.

Context domain	Description	Wendi (paint)	Glowing
Knowledge domain	Scientific ideas in class are accountable to and informed by other domains of knowledge.	Knowledge from art (that red is a primary, that there are low and high quality colors) is used to dispute our model for color mixing.	Knowledge about the moon (that it reflects light) is invoked to explain our model for pinhole cameras.
Physical context	Objects used in class are not solely classroom and lab equipment; objects from other physical domains are used in the development of scientific ideas.	Oil paints and data sheets from paint companies are brought into class to dispute our model of color.	Evidence for and against the model are not typical: cartoon representations of glowing; neon lights; a spotlight in a theater; tapes of dancing under a spotlight.
Temporal context	Ideas are positioned as accountable to future ideas and information; ideas are not settled.	Our model for color is not 'solved' and finished, but accountable to ideas introduced at any time.	N/A
Functional context	Objects and concepts break from typical functions as they are used to address scientific ideas.	Wendi's oil paints are typically used for painting; here the data sheets and properties are examined to develop a model.	Tapes made of dance performances and cartoons are used as evidence for and against our model of light.
Social context	Non-academic/scientific social identities are positioned as important and relevant to our inquiry.	Wendi's identity as an artist and expert on color is brought into the classroom.	Sarah refers to herself as a dancer in providing evidence: 'I've danced for my whole life and. . . '
Modality	Modalities that are not typically employed in scientific contexts are engaged to advance scientific inquiry.	Oil painting, color palette.	Cartoons, singing, hand motions, diagrams, and materials are all used in developing and vetting the ideas.

is reason to suspect that such a blending of contexts in the classroom is consistent with aesthetic experience, as described below.

First, we note that many of the examples offered above are, using Wong's criteria of transformative, unifying, and compelling, aesthetic experiences. Drawing on the examples in Table 3., Wendi's experience is highly **compelling** to her: she experiences 'angst' - a frustration that the red pigments in class are not behaving as she knows a quality red to behave. This lack of coherence compels her to bring in examples from out of class, using her own materials as evidence for our activity; she **unifies** the classroom conversations and definitions of 'primary color' with her own understanding. The work is **transformative** as she sees color as both an artist (familiar with the quality of a red oil paint suitable for mixing) and now as a scientist (analyzing the absorption spectrum of paint in defining color).

Similarly, in the conversation regarding glowing, this, too, is **compelling**, or 'saturated with emotion.' Alyssa expresses vexation or angst, her tone frustrated as she says 'the chair is not *glowing*.' There is then a playful tone as the class chases a range of ideas, singing, drawing, and recalling dance performances. In those range of examples, we also see evidence of **unification**, both of *ideas* as a wide range of examples are aligned under our understanding, and a unity of *experience*, as the emotional, intellectual and practical all have relevance. And finally, there is a clear **transformation** in perception: students 're-see' the moon's glow, the cartoon drawings, the glowing dancer on stage through a scientific lens.

We also see evidence of transformation, unity and compelling experience in some of the more brief examples: as Johnny describes the feeling of a loud blast moving through him, he is 're-seeing' the prior event, now as a science story of what sound is and how it moves through things; there is a unity in this as he describes the sound, visual, and the feeling, as they connect to the broader scientific idea; and there is a strong emotional valence in the description and in peers' response. As Steven refers to the slide getting hot in the sun, he does so with a sense of discovery - looking around the room with a smile as he describes the slide as evidence for his claim.

These moments in class, then, selected because of their blending of contexts, are also frequently rich aesthetic experiences in their own right. And so IC supports aesthetic experience not only by promoting transfer of scientific activity to out-of-class settings, but because when in-class scientific activity is richly intercontexutual, it is often an aesthetic experience of science.

5.4. Summary

In this section I have adapted the taxonomy of transfer from Barnett & Ceci to construct a taxonomy of intercontextuality that may be present in science classrooms (summarised in Table 3); all IC examples in the table are taken from the Scientific Inquiry class.

These contexts, of course, are not orthogonal: when ideas from bartending are introduced in physics class, a rich set of contexts are presented intercontextually: physical, knowledge, functional, social and modal contexts that are not usually relevant in physics class are brought to bear. The taxonomy is provided to point to ways in which various contexts — contexts known to be relevant for transfer — can be positioned intercontextually during learning.

Examining the descriptions of IC in Table 3, I note that many science courses and curricula are not designed to be intercontextual. That is, reform curricula that engage students in reasoning deeply through a sequence of ideas, with materials designed or curated for their ability to promote conceptual change, may not promote rich aesthetic experiences in other contexts. Below, I describe features of the Scientific Inquiry course that I believe make it so richly intercontextual, and that account for students' self reports of aesthetic experiences related to the course.

6. Teaching for everyday aesthetic experience of science

6.1. Current conceptions of teaching for aesthetic experience

Aesthetic experiences of science in everyday life are rarely achieved by teaching canonical content in traditional classes (*e.g.*, Atkins & Frank, 2015; Pugh et al., 2010). Pugh, Girod and colleagues, whose work informs much of this study, offer suggestions for teaching for aesthetic experiences. These methods draw on their definition of the construct of aesthetic experience (e.g., 'expansion of perception,a' 'experiential value' and 'motivated use'), and empirical studies in which teachers explicitly attend to those constructs – for example, by highlighting for students the historical context of discovery, fostering anticipation, modeling a passion for the content, and using metaphors to expand perception – demonstrate clear gains around those desired constructs (Girod et al., 2003; Pugh, 2002; Pugh & Girod, 2007).

Wickman (2006, p. 47), however, notes that Girod and Wong (2002)'s definition of aesthetic experience 'risk[s] rendering aesthetics as something of mere form that could be as easily added to science education as a new and more gaudily colored wall paper in the classroom. ... It is hardly helpful to say that if we make science more compelling or fun to students, science *is going to be* more compelling or fun to students...' Indeed, the methods applied are techniques that are easily added to a traditional curriculum.

Although Wickman's concern does not bear out in their empirical studies (students report that the concepts are, indeed, more compelling when the teacher presents them as such, and they seek out more opportunities to learn and apply their scientific knowledge in everyday life), there remains the concern that those instructor-driven methods may limit the scope of this 'transfer' and the nature of aesthetic experiences in novel contexts.

6.2. Teaching for intercontextuality; teaching for aesthetic experience

In contrast to the methods advanced by Pugh and Girod (2007), this article suggests that aesthetic experience of science in students' everyday lives is supported by engaging students in the development of ideas that are consequentially informed by a wide range of contexts that students themselves bring to bear in class: the social, functional, knowledge, modal, physical contexts of their own lives. In this way, scientific content and scientific activity are inseparable from students' lives as a bartender and a soldier, to the cartoons in the paper, relevant to the paints they use as an artist, visible in the drugstore and on a dance stage, and reflecting back in a spoon.

In most classrooms, however, the teacher 'has the privilege of pointing out the objects, events and states of affairs to enter the field of shared attention' and students are required to 'accept and engage in whatever social reality is introduced' (Rommetveit, 1976, pp. 96 - 96). This role for the teacher, of course, can be viewed through a lens of fairness: it seems unjust to ask students questions without providing the resources to answer them, or ask them to use data and evidence we did not also guide them to collect. Letting students leave classrooms with 'misconceptions,' may limit successful participation in a scientific community. And the quality of students' ideas, it is reasonable to assume, should be assessed by someone with expertise in the subject. However, this limits students' connections to the content of our disciplines and agency within those disciplines: school subjects become an encapsulated world, removed from their everyday lives, assessable only by experts (*cf.*, Atkin & Coffey, 2003). It is even more removed for those whose cultural contexts are not well represented in the classroom.

Below I describe methods taken in Scientific Inquiry to support intercontextuality. This is intended as an overview and a counterpoint to other approaches at teaching for aesthetic experience, rather than a complete description of the methods and their rationale.

6.3. Disruptions

The approach we take in Scientific Inquiry for engaging out-of-class contexts is that of designing disruptions, as Ma (2016) argues. When designing disruptions:

> Certain typical classroom resources are made explicitly unavailable through these disruptions, and so a setting is created in which it is reasonable and even necessary for students to draw from their nonclassroom repertoires of practice... disrupting a setting disrupts both ongoing activity and how participants experience and understand the spaces of activity. (p. 6)

Ma (2016) goes on to note,

> [A] balance, between existing or implied cultural meanings and those students are invited to recruit, is in constant motion (and tension) in this kind of design. It can be struck as long as students are positioned with conceptual agency (Boaler & Greeno, 2000; Gresalfi & Cobb, 2006)—they must be active participants in the making and negotiation of

> meaning and inventing or selecting of strategies for problem solving, in part by recruiting resources of their choosing that may be unanticipated by or unfamiliar to the teacher or instruction designer. (p. 8)

Disruption, then, when positioned with conceptual agency, has parallels to Brousseau's (1997) devolution: 'the activity of the teacher in attempting to induce the student to take on responsibility for a Situation.' That is, for students to invoke other contexts in the development of scientific ideas, instructors must confer power on them - power to define what ideas and contexts are relevant and worth pursuing; in doing so, the instructor loses control over the kinds of ideas and contexts that are invoked and the direction that our curriculum might take.

Though disruption and devolution were not design principles we explicitly used as we developed the course, we can identify multiple forms of disruption and associated devolution in the Scientific Inquiry course. These disruptions are departures from typical science courses, and function to promote the recruitment of other contexts, in particular because they require students to draw on their own resources as they work together to construct ideas. They are disruptions disruptions ('typical classroom resources are made explicitly unavailable') that are associated with devolution (a transfer of power to the students). These include:

- Student authoring of questions.
- Lack of traditional lab equipment.
- Lack of traditional information resources.
- Student assessment of scientific models.

Each is discussed in turn below.

6.3.1. Disruption/devolution via student authoring of questions

The units of inquiry begin with a question ('Is every color in the rainbow?' 'Does the pitch increase or decrease as I add water to a glass?') or puzzling phenomenon (pinhole cameras, eye dissections, dismantling clocks, observing a Gaussian gun). From here students begin to construct models and generate problems. These are the first disruption, and a critical one: when the teacher has not authored the particular problem for students to solve, the students can no longer assume that the teacher has curated the necessary materials to address the problem, nor that the instructor knows the answer (in fact, students in the course will often ask the instructors if they know answers to the problems students are pursuing). This allows for a range of contexts to be engaged in the course.

6.3.2. Disruption/devolution via the lack of traditional lab equipment

In class we have a cabinet with a range of everyday materials students may use: tape, construction paper, paints, food coloring, flashlights and laser pointers, tin foil. We choose materials that are inexpensive and accessible. Unlike most undergraduate labs, these materials are ones students feel comfortable repurposing, as when one student draws on the flashlight reflector to trace rays, or dismantles a child's plastic clock to remove its mainspring. The laser pointers are cheap keychains, and a student embeds one in her jell-o (a gelatin snack) to see if rays bend inside the material. Without the curated box of convex and concave lenses, marked with their focal length, students use their own glasses. Without a set of mirrors, we use spoons. These disruptions, then, require students to draw on physical contexts from outside the classroom, and to repurpose those in the classroom. Models of light might be applied to and noticed in any object, not simply optics equipment sanctioned by the instructor.

6.3.3. Disruption/devolution via the absence of traditional information resources

There is no textbook or lab manual, we ask students not to 'google answers,' and the instructor serves to facilitate conversations and highlight particular approaches, but not to provide answers. (After the end of a unit, we have 'answer day' in which the instructors answer all questions as completely as possible.) In this way, students generate and justify models using ideas from a range of social and knowledge domains, and the ideas we develop are then accountable to and relevant in those domains.

6.3.4. Disruption/devolution via assessment of scientific models

Related to the disruption in information resources is the disruption in the assessment of students' ideas; not only does the instructor not provide 'right answers,' neither do they assess students' answers. As students' ideas are developed in class, they are evaluated by other students in light of those students' ideas, data, and models. Homework is graded, but the instructor evaluates these not for correctness, but coherence, mechanism, and clarity. In this way, a strong, well-regarded idea may ultimately prove incorrect, and so ideas are never fully endorsed but subject to revision, accountable to future ideas and new data, fostering, in particular, the temporal IC.

Temporal IC stands in marked contrast to typical science classrooms that progress from correct idea to correct idea, and students are often shocked when they first realize many of the ideas taken up in class are incorrect. This was expressed by a student who, after the class spent several days developing a model for why brown is not visible in the rainbow, found their model to be wrong while painting in her lab journal. She emailed the professor one night, noting, 'I am freaking out about brown (in a good way.) ... I could not stop thinking about the color brown tonight, so I did some science journaling and brown is all the primary colors... I can't believe that you listened to us circle the drain for so long with a straight face.'

7. Conclusion

In this article I take the perspective that a primary goal of science education should be to foster uniquely scientific aesthetic experiences in the world. As an example of such engagement, I offer the example from Maddy, who proudly confirms a predication regarding the shape of glasses in a Walgreens. I argue that this aesthetic experience is not one in which ideas from class are transferred to Walgreens, but instead is an example of *intercontextuality*: when ideas and activities from class extend into out-of-class contexts, consistent with other perspectives on transfer (*cf.*, Bransford & Schwartz, 1999; Goldstone & Wilensky, 2008; Wagner, 2006). I suggest that these experiences that happen out of class are supported in classrooms that are themselves intercontextual in consequential ways: when other contexts are leveraged to develop and vet scientific claims. I adapted Barnett & Ceci's taxonomy of transfer to characterise six related domains of intercontextuality, and exemplified these with vignettes from the Scientific Inquiry course. Finally, I turned to characteristics of the classroom that, I hypothesise, support intercontextuality: characteristics that disrupt typical classroom structures in ways that confer power on students. And I have suggested that such intercontextuality allows students to leverage 'their diverse repertoires of practice and histories of engagement in cultural practices' (Ma, 2016, p. 2) in ways that position these practices as assets for scientific progress.

With this list of disruptions, I do not mean to imply that consequential intercontextuality is so easily engineered. In the 14 semesters that I have taught a version of this course, there have been semesters that are richly intercontextual and playful, where students, at the end of the semester, suggested we might continue through the summer just for fun. Students are often eager to meet the spouses and children who have been mentioned in class and organise end-of-term celebrations. However, there was one semester in particular in which students steadfastly resisted; conversations were far from playful, and rich, insightful moments were rare.

Moreover, I have not discussed a range of features of the course that I believe contribute to intercontextuality beyond these disruptions, or support students in managing those disruptions. These include: the choice of topics, the curation of materials, and how assessment happens in this context. Clearly, simply removing information, removing lab materials, and allowing students to author questions, answers and their assessment is not all that is needed to support this kind of inquiry and intercontextuality.

And finally, I recognise that these disruptions are not easily implemented in many classroom settings. The Scientific Inquiry course describe here is not a prerequisite for other courses, nor does it explicitly prepare students for exams as many college science courses do (e.g. exams for future physicians, doctorate degrees, or engineering licensure). That is, while we were confident that students would learn a great deal about the topics we studied, we did not prescribe in advance what ideas would be developed. Instead, we titled the course 'Scientific Inquiry' and our learning outcomes were concerned with students' engagement in scientific practices. Few courses have such leeway.

Nonetheless, I hope that these queries can be useful when designing a science course that sets aesthetic experience as a goal:

(1) How does imagining a students' aesthetic experience in the world as continuous with classroom practice - and not a transfer of content - shift the kinds of activities and content addressed in class?
(2) When scaffolding instruction for particular content ideas (e.g., by adding in structures, equipment, and processes similar to those in a physics lab), are there ways in which those are limiting opportunities for intercontextuality? Can similar goals be reached while still allowing students power over the construction and vetting of ideas?
(3) How can ideas - even ideas seemingly 'settled' - be positioned as tentative, open to ongoing evaluation by the students (e.g., Atkins (2012)) so that ideas are challenged and improved over time?

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