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Resonating with physics: physics students' stories about existential and affective relations to science in and beyond formal learning spaces

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ABSTRACT

In this paper, we seek to contribute to understandings about how physics allows reflection on what it means to be human. Drawing on life-history interviews with three university physics students, we explore the affective and existential aspects of engagement in physics, with attention to experiences from informal and formal science spaces. With Hartmut Rosa's conceptualization of *resonance*, we show how (intertwined and parallel) relations to physics – as a superstructure, science materials, and people via science – can provide meaningful connections to the world and oneself. The students, all of whom had undertaken adult education, had enrolled in university physics for reasons of awe, joy, and, also, serenity in hardship. Though reiterating common understandings of physics as an 'objective' and 'challenging' subject, the interviewees described their engagement in physics as salutogenic. Physics provided existential meaning and well-being; e.g. its epistemic character of boundaries and beauty offered stability in precarious life situations. Our study shows how science can be important for (i) reshaping one's worldview and self-understanding, (ii) fostering meaningful relationships, and (iii) enhancing well-being. We conclude that to cultivate engagement in science, education should prioritize creating meaningful, respectful learning spaces that support students in forming a diverse range of resonant science-related relationships.

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Introduction

Science, especially physics, is often perceived as objective, universal, and cultureless, as a way of approaching and appropriating the world with reason. Traweek (1988), in her ethnography of (high-energy) physicists describe how they imagine physics as 'a culture of no culture, which longs passionately for a world without loose ends, without temperament, gender, nationalism, or other sources of disorder – for a world outside human space and time' (p. 162). In this way, physics becomes the very pinnacle of scientific objectivity. This perceived universality and objectivity of physics strips the scientific process of all human involvement, presenting the practice of physics as an entirely rational process.

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However, the vastness and complexity of the discipline allow different tales of physics to be told, including those of 'trembling experience[s]' (Nicolaisen et al., 2023, p. 226, drawing on Martin Wagenschein). Physics, suggested to be fundamental for the sciences (Girod, 2007), tackles questions about the origin of the universe, but also includes applications such as materials science; it is a study of 'nature' that ranges from the structure of our cosmos to studies of the smallest building blocks of matter. When physicists describe their work in biographical or popular accounts, affective and aesthetic utterances are abundant. Fundamental equations in physics are often talked about as elegant, and mathematical beauty has even been seen as a methodological principle for some, like the theoretical physicist Paul Dirac (Hovis & Kragh, 1993). Mathematical beauty here is concerned with the simplicity of equations and the possibility to represent a theory as elegantly as possible, in its most extreme form embodied by the search for a 'theory of everything' (Ellis, 1986). The physicist and science communicator Jim Al-Khalili (2022) writes in *The Joy of Science*: 'Science gives us a way to see the world beyond our limited senses, beyond our prejudices and biases, beyond our fears and insecurities, beyond our ignorance and weaknesses. Science helps us to see through a lens of deeper understanding and be part of a world of light and color, of beauty and truth' (p. 161).

To learn about the role of science in people's lives, we need to move beyond 'connecting the dots' of activities in science, as becoming *in* and *through* physics is 'tied up in complex ways with a web of meanings and practices that constitute learning lives' (Rahm et al., 2022, p. 4). In this article, we investigate the life histories of three 'latecomers to science' (Jackson & Seiler, 2013, p. 826). Unpicking this web, we trace the meanings these physics students make of physics in their lives across time and space. The aim is to explore affective and existential aspects of engagement in physics, with attention to how informal and formal science spaces can contribute to well-being and self-formation. By unfolding tales about physics from this perspective, we seek to contribute with empirical and theoretical insights for more inclusive and thriving science cultures (Nicolaisen et al., 2023).

Engagement in learning physics

All humans do not partake on equal terms in the purported cultureless physics culture. In the West, university physics education and academia recruit predominantly white men with academic backgrounds (Skibba, 2019). Engagement is cultivated and hindered by practices and social relations in and outside educational institutions. Studying young people's aspiration for STEM, Godec et al. (2024) show that access to science capital – such as science experiences in and outside school and practical knowledge – foster engagement but are unequally distributed. Furthermore, they suggest that identifying as a 'science person' is more important than accumulating extensive science capital for pursuing a STEM degree. Studies in feminist epistemology (Harding, 1991) and science identities (e.g. Avraamidou, 2022) argue that discourses of gender, race and ethnicity inform who can be recognized as a 'science person' and as possessing the required objective outlook. In addition, school physics is entangled with notions of cleverness and intelligence (Archer et al., 2020) and university physics education is perceived as accessible only for a few (Skibba, 2019). Why is that? According to Louise Archer et al. (2020), school physics does 'pedagogic work' that keeps people out. Consequently, classroom practices that align physics with cleverness or that continuously defer the 'interesting bits' to a later stage are not just happenstance – they play a key role in the reproduction of physics as an elite subject by restricting both the number and diversity of those entering the profession. Physics is able to maintain its high status in relation to other subjects, by the very same pedagogical practices that cultivate mis-recognition and restrain engagement and science aspirations.

Even though science holds attraction for some students because it is 'logical and has strict procedures' (Holmegaard et al., 2014, p. 198), some prior research emphasize how affective experiences in science are important for instilling a sense of wonder and curiosity that encourages learning and research (Cuzzolino, 2021). However, this is seldom the case when scientific knowledge of physics is

transformed into school physics, which is perceived by many students as dry, boring, and stripped of context and real-world relevance (Nag Chowdhuri et al., 2023).

Feelings that are experienced and expressed when constructing knowledge and in reflection on that knowledge can be called epistemic affect (Davidson et al., 2020), e.g. awe (Cuzzolino, 2021) and frustration (Jaber & Hammer, 2016). For example, studying dispositions of feelings, Jaber and Hammer (2016) argue that scientists are encultured into 'perceiving confusion as motivating, associating puzzles and uncertainties with pleasure' (p. 194). Nevertheless, affective experiences from science-related activities and conversations have implications beyond professional aspirations and learning. Cuzzolino (2021; see also Girod, 2007) shows how scientists' experiences of awe can foster altruism and 'connectedness' (p. 696), and change one's relation to the world.

Theoretical perspectives

While questions of science identity and science capital allow critical explorations of *for whom science* is valuable, we, similar to Nicolaisen et al. (2023), aim to explore *why science* is meaningful for people. We believe that science education, like social research in general, needs to address inequality beyond resources and recognition, as emancipation necessitates meaningful relationships to the world. To conceptualise the role of physics in participants' lives, we turn to Hartmut Rosa's sociological theory of world relations.

In physics, resonance refers to the phenomenon when a system vibrates at its natural frequency in response to an external force. Similarly, Rosa (2019) conceptualizes *resonance* as a responsive, transformative relationship, characterized by unpredictability and curiosity, where the subject and the world resonate with each other, neither echo nor absorb. We use this to explore the link between physics engagement and well-being in the students' life stories and analyse the students' senses of connection, their physics-related resonance relations. Resonant relationships are enabled by self-sustained subjects' agentic attentiveness to the world and formed by the affect (e.g. a positive or negative epistemic affect) that this encounter brings about. Its contrast is relations characterized by *alienation*, i.e. muteness, indifference and 'no meaningful inner connection' (Rosa, 2017, p. 46). Disconnectedness from the world or oneself, 'is the result of an encounter between the subject and the world in which their assimilation fails in a fundamental and lasting way' (Rosa, 2023, p. 138). Rosa (2017, 2019, 2020) argues, that what people experience as a 'good life', is an everyday life with access to resonant relations to the world and oneself: 'The receptive as well as active connection brings about a process of progressive self – and world-transformation' (2017, p. 47). Thus, we see well-being as a continuum, conditioned by culture and shaped by the subject's agentic strategies and evaluations.

People's capacity for forming and maintaining resonance relationships resides in spaces that are neither rigid not shapeless, and is conditioned – not determined – by cultures and institutions, and therefore unequally allocated. School at its best, Rosa (2019, 2020) concludes, similar to arguments from a Bildung perspective (Nicolaisen et al., 2023), functions as a resonant space for both teachers and students, and allows for cultivating young people's capacity and roadmaps for resonance. School can also imply weary hours of repeated failure and test anxiety, inadequate teaching, chaotic or overly-disciplined lectures, loneliness and hostile relations, etc. At its worst, it is a space dominated by 'social alienation that leads to an erosion of interest and […] self-efficacy' (Rosa, 2019, p. 242), that mute students' relationships with the surrounding world in the present and future. Overall, fear and mis-recognition (of capacity and motivation) are acknowledged as detrimental, as these block and rupture resonance relations in learning situations and beyond.

This study attends to relations that interviewees make sense of as engagement *in physics* or *by means of physics*. Rather than enforcing organizational boundaries and disciplinary definitions to distinguish physics from non-physics experiences we attend to what the interviewees describe as physics experiences. These relationships may be temporary or prevailing and of various kinds. Rosa (2019) distinguishes between three types of axes of resonant relations: *horizontal axes*

(subject/human); *diagonal axes* (subject/objects); *vertical axes* (subject/existential dimension). Creative, absorbing and pleasurable human relations formed by means of science, e.g. joint interest in or aversion for science can be a fundament for developing horizontal axes of resonance. The previously introduced sublime experiences (wonder and awe, Cuzzolino, 2021; aesthetics, Girod, 2007) from ideas and their form in science and mathematics are conceptualized as diagonal axes of resonance, between subjects and materials such as physics books, and laboratory equipment. However, if the same sublime experiences are related to a 'totality that exceeds the individual' (Rosa, 2019, p. 40), this is referred to as a vertical axis of resonance. Late-modern society, praising scientific rationality, Rosa argues, restrains peoples' capacity for forming vertical axes of resonance, especially in adulthood. Still, he points to nature as a sphere for existential connectedness, mirroring research in religion studies that shows how people in secularized societies experience 'transcendence' in nature, without need for social organizations or dogmatic superstructures (Thurfjell et al., 2019).

Methods

The analysis presented is based on three life history interviews with university-physics students from a larger project about trajectories into higher education physics in research-intensive universities in Sweden (see Johansson et al., 2023). Like all interviewees, the focal students (Tobias, Tina and Kamal) were self-selected minoritized students in physics (i.e. not white men with academic backgrounds). An open call for participants 'from underrepresented groups' in physics programs were made on campus though posters and information from course coordinators or researchers: 'We aim to gather diverse perspectives on what has sparked interest in and facilitated transitions to studying science at the university level, and will be interviewing students from various backgrounds.' The interviews were conducted in 2019 and 2020; Tina and Tobias were interviewed face-to-face, while Kamal, due to the pandemic, was interviewed online. All three are first-generation students, who had supplemented their diplomas to gain qualification for higher education science.[1] Detailed biographies are available in the findings section.

Exploring the students' lived experience from childhood to present, we utilized graphic elicited interview methods: timeline interviewing (Adriansen, 2012). Sheridan et al. (2011) argues that timeline interviews 'pulls together rich data, promotes narrative accounting, and allows both participants and researchers to focus in on specific aspects of the data to deepen and enrich storytelling' (p. 565). As such, the multi-textual characteristic of the timeline allowed the interviewees to construct a comprehensive, complex life story in the interview situation about themselves, their lives and physics education, and bring experiences, movements and agentic choices to the fore. Life history interviews in general, with their chronological organization, can augment linearity and causality in the narratives. Although the narratives are not unmediated recollections of events and experiences, utilizing a visual timeline facilitates memory recall and functions as a structuring device (Bremner, 2020). This makes it 'possible – both for the researcher and for the interviewee – to "jump" in the story/interview' (Adriansen, 2012, p. 49), as it allows the interview to pause at particular occurrences, contemplate, exploring small stories as well as 'blank spots' on the timeline, while not losing track of the overarching life history.

The interviews commenced by asking the interviewee to draw a timeline that illustrated their path until today, and to choose a starting point for their story.

> Interviewer: 'Draw a timeline that illustrates your path until today, from birth to [YEAR of] enrolment and now [AGE]. On this line, it is intended to capture, for example, turning points, important events, and significant people. Where do you want to start your story?'

Through the dialogue, different aspects of the interviewees' lives and relationship with science were made meaningful – intelligible in relation to everyday life, events, and encounters, as continuity and turning points – and used to position them. Simultaneously, the interviewee and interviewer (Nyström or Danielsson) worked collaboratively to visualize the interviewee's path to higher

education in physics using an A0 paper, pencils and sticky notes in various colours (for details, Gonsalves et al., 2023). While the primary focus was on engagement with science/physics throughout life, the interviewers allowed other stories to unfold.

Interviews were selected based on an analysis of choice narratives from the full data set (Johansson et al., 2023). The chosen narratives emphasized emotional stories of physics as an enabler, rather than focusing on what made choosing university physics possible. Selected interviews (60-120 minutes) foregrounded well-being and life-transformation through physics; these were emotional, elaborated stories. The interviews were analysed utilizing thematic narrative analysis (Riessman, 2008). Five themes were identified: (I) physics as beauty and boundaries; (II) adversity in childhood; (III) alienation from everyday lives; (IV) informal physics for well-being; (V) formal physics education for emancipation. Surveying the entire dataset for additional interviews including these themes, we found that I and II was recurring, III was present in two more interviews, and IV and V were absent in the rest of the dataset. This reassured us that the initial selection of the three interviews was valid for the analysis of well-being from physics. Lastly, the themes were analysed theoretically. The analysis is reported thematically in the three findings sections (i.e. I-III; IV; V).

The study has ethical approval from the Swedish Ethical Review Authority, and all interviewees have given informed consent. The interviews were conducted in Swedish and transcribed verbatim. Identifiers have been removed or replaced with more general terms, all names are pseudonyms.

Resonant and mute relations in the students' life stories

> It's just that love I really want to try
> before I die
> because I want to give it a try
> just to have
> So, I really want to give physics a go
> because there is something deep,
> almost religious too
> within me.
> The thought of understanding a small detail of nature
> makes you feel a little more
> it is something rather magical.
> And it feels like
> I think it's really beautiful.

The words about love, awe, and beauty come from the interview with Tobias[2], and are illustrative of all three students' motives to enrol in university physics education. All three had completed Swedish upper-secondary school, but graduated from programs that did not make them eligible for higher education science studies, and enrolled in university physics via adult education after several years of work in other professional fields. In various ways, they had encountered adversity in their childhood and youth, and to differing degrees also as adults. Relationships with the natural world were recognized as vital for managing these conditions. In this section, we introduce the three students' life stories, providing short biographies, and thereafter an analysis with attention to vertical, horizontal and diagonal axes of resonance in their lives.

Tobias's story is of a childhood in a small working-class community in rural Sweden, with accommodating parents and scarce economical, educational, and cultural resources. The relationship with his older brother, who pursued an educational trajectory in science, is crucial. Sharing a fascination for physics, they, in company with his brother's friends, formed a steady axis of resonance. In spite of this, and watching popular science media since his early teens (Danielsson et al., 2023), his curricular experiences are mute. Tobias was always in rather boisterous classes and describes his classmates as generally uninterested in education. He attributes his own good grades to eloquence, rather than actual understanding. He struggled with high-level mathematics and

chose a vocational program in upper-secondary school, which he pursued into higher education and a professional career. Throughout his life, Tobias has struggled with mental health issues – 'it's chaos in life' – and the related problems to imagining a future. For many years, physics 'was the love that slipped away', Tobias said, 'I'm thinking that I get to yearn but it'll never be us.' Still, physics offers stability and tranquillity:

Tobias: I've had a lot of conversations with my girlfriend about this too.
Interviewer: I understand.
Tobias: She's a humanities person who has studied a lot of philosophy and that kind of stuff. And I've been around people a lot, like all the time, this is kind of … For me, physics is something that represents something that has nothing to do with people. To constantly try to disregard one's own ways, natural patterns of thinking and really try to structure one's way of thinking and get to something a little closer to reality. And in that way, it feels a little more genuine, a little less focus on trivialities. Although you study, of course, things that are so small and insignificant, practical details, it is beautiful in itself because you also take a stand and say 'I don't want to care about what happens on Facebook and what's happening in the news and stuff right now, because I have to figure this out.

Tobias draws on love and magic for conveying his relation to physics as a profound relatedness to something that transcends the human and physical world (Rosa, 2019). For Tobias, physics enables a displacement of the focus from his and other humans' everyday life and internal struggles, which serves a healing function.

Tina's story is one of a childhood with physically and emotionally absent parents, mostly being raised by older siblings. Her economically strained working-class family moved between several suburbs around the same larger city. Her childhood-home as well as school are mute spaces, dominated by loneliness and hostile relations. Her experiences of school were highly negative, and she expresses a strong contempt for several of the teachers. Following neglect and harassment in school, she says, her adulthood had to a large part been characterized by very low self-esteem and mental health problems, and years of manual labour. She discloses a life-long interest in science combined with low self-efficacy in formal science education and beyond. In her story, childhood moments of stargazing are at the forefront. These are recalled as moments of a deep connection with the universe during childhood but also something to direct herself towards when recovering from mental illness later in life:

Tina: Somewhere around here [points to a few years back at the timeline] – I came to remember all these things – yeah, that was here [points to her early childhood years at the timeline] – when I was a child and was looking out … so, every winter I was counting all the stars in Orion and looking for the Pleiades and … Ah, 'now this is beauty – the universe; that's what makes my brain turn on!'

In Tina's story, stargazing brings about intense aesthetic and affective memories of beauty and meaningfulness; exploring the starry sky instilled a sense of connection to the cosmos and fostered embodied feelings of awe as a human being, making existence and life meaningful.

Kamal's story involved a childhood with absent parents, albeit spent with a caring extended family. Growing up and attending school in a mid-sized Swedish town, Kamal describes his peers and schooling in a positive light, but also reflects on his strategies to negotiate being racialized in an overall white community. School, however, in line with his home, is portrayed as a space that encompass resonant relationships in spite of adversity. His family had substantial cultural resources, with several relatives involved in the creative arts, and until recent years arts had been a stable axis of resonance. He was recognized for his creativity in school, but beyond that relatively low-achieving. Subsequently Kamal's later school years involved a focus on creative arts and he pursued a prestigious further education in the arts and had worked professionally in this field for several years. However, it is the ocean he turns to for comfort when handling difficulties:

Interviewer: So, you are at that point taking interest in the environment, climate, and large complex systems?

Kamal: Yes, precisely, yeah. And I'm thinking that the ocean and the weather, it is something that I feel, I get … Whenever I'm in [home town], I want to spend time by the ocean, and go there for walks. It is something like … I get such a … precisely that magical feeling. It's just such a large amount of liquid that, in principle, kind of determines everything on the planet but that is still so fragile in a way. […] Well, people die, just like that. They go for a swim in the Bay, and suddenly they're pushed out by an undercurrent, and suddenly a life is just gone. This power of the sea was very important for me then [in childhood].

Kamal speaks about the ocean in symbolic and existential language. As a child and later in life, he resonated with wonder and serenity when confronted by the vastness and omnipotence of the ocean; the ocean provides and takes life.

Horizontal axes of resonance by means of science and with science people are made important for the students' trajectory towards university physics. Their engagement in physics and physical phenomena does, in various ways, involve other people and building a joint relationship in the discipline. Tobias said: 'I had my brother and his friend. When he [the friend] visited us, we lay awake at night and talked about black holes. Such things.' Thus, vital for both well-being and identity, his main resonant relations are built on conversations about science with peers that were scientists-in-becoming. Tina's interest in astronomy was also partly shared with her mother. Even so, she describes stargazing in childhood and youth primarily in the outskirts of the suburb as a solitary experience, on a few occasions shared with peers. There, in the outskirts of the suburb, lying on the ground gazing at the stars, she felt relaxed and playful from the She also formed stable resonant relationships as a young adult with her (former) partner and his family. This social space was financially precarious but abundant in scientific knowledge, she explains: '[We could] discuss really deeply, both science and philosophy – I got stimulated by this, we had so much fun.' Apart from the meaningful and stimulating connection to other people, these experiences of joint explorations of 'grand' things represents a period of well-being that aids her recovery and informs her choice of higher education. For Kamal, like Tina, science was made part of his everyday life in a romantic relationship with a child of scientists: 'then it [a scientist] was very much something that I felt I really didn't want to be, but still something that existed'.

Kamal also talks about how working collaboratively with physics during the foundation year had brought a lot of joy, and how it provided a way of linking up with the everyday world that is described as magical.

Diagonal axes of resonance with various science-related learning materials are outlined in the interviews as important for their choice of higher education. While all three relate to how the materials in school science seemed uninteresting, Tobias brings forward the interest he took in his brother's homework and Kamal discloses when detailed lab reports during teacher training suddenly came alive and shifted his ideas about the science profession. Tina recalls being bolstered with children's 'books about dinosaurs and whales and dolphins and stars'. In retrospect, it is described as an act of love: 'someone had sort of seen and listened to me about what I thought was exciting'. Tobias speaks about resonant readings by Lawrence Krauss (theoretical physicist) and Carl Sagan (astronomer), and 'watching physics lectures late at night' on the internet. As an adult, Kamal begins watching popular science channels (e.g. Sixty symbols) produced by physicists for fun.

Science as a vertical axis of resonance has, most tangibly, a prominent place in all three stories. Similar to what is traditionally reserved for religion, as exemplified above, Tobias speaks about his devoted relation to physics conceptualization, while Tina and Kamal make sense of their profound relation to cosmos and the ocean as contemplative explorations of the world of matter. They resonate in a connection to 'something bigger' and beautiful. The sense of the vastness of the ocean or the universe, or a sense of grasping the world through physics, is described as liberating by our interviewees as it puts their life in proportion. This is similar to Thurfjell et al.'s (2019) findings, where they describe how nature is experienced as something that 'transforms both one's mood and one's sense of time and space into a liberating experience of freedom, awe, and respect'

(p. 202). With natural science as a kind of superstructure, physics is described as life-giving and transformative.

In the students' stories, physics-related experiences are brought forward to make the trajectory into university physics intelligible. The above outlined axes of resonance – ranging from encounters with attentive relatives and digital materials to the non-human universe – are deemed important to various degrees, and some are intertwined.

Physics as a sphere for well-being

Strongly aligned with masculine intellect (Archer et al., 2020), physics is often considered a 'hard' science, both as in providing objective knowledge claims and as in difficult (Schiebinger, 1999). Learning spaces imbued with potential for 'instrumental interactions' (Rosa, 2019, p. 226) and threats to self-efficacy, can be anticipated to close off resonant relations, in particular for minoritized students. However, the stories of our interviewees demonstrate how different axes of resonance in the physics sphere provide profound comfort and joy. Well-being from engagement in and by means of physics, is further explored in this section.

First, and most prominently in the interviews, physics was a sphere in which they found meaning. As described above, the students brought forth how physics (i.e. experiences from conceptual physics, cosmos, and the ocean), connected them to something profound and beautiful. Furthermore, as exemplified with Tobias's story below, the everyday experiences of resonant relationships provided meaning in their lives. For him, physics as a field of knowledge made him at ease, and meaningful relations were formed from lively conceptual examinations with other people at home and in school. Crossing spatial boundaries of his upper secondary school, during recess he walked from the part of the school where his vocational program was situated to that of the science program. He left his friends to instead seek out teachers he could talk physics with:

> *Tobias*: I often went to the science program and there were teachers I could ask questions to during the breaks. And they said, 'Yes, come into the teacher's room and borrow this book from me.' And they talked to me seriously too, and like, they were very happy that I was interested. So, it was the first time I realized that there are people who want to talk about these concepts. Even though you cannot calculate and so on. It was super super beautiful.

With these upper secondary school physics teachers, Tobias forms resonant teacher/student relations and relations to books about physics beyond curricula. He described the interactions as built on mutual joy, curiosity and respect; they recognized science as a serious matter and him as intelligent, despite his struggles with mathematics. Though physics stayed mute during earlier formal lessons, he developed relations to humans and materials in the physics sphere by unconventional means.

Second, as disclosed by Tobias and Tina, engagement in physics was helpful in managing mental illness. For Tobias, the predictability and regularity of physics had provided an anchoring in a rather chaotic life. Physics provided the structure and beauty that enabled him to establish resonant relationships with the world and himself.

> *Tobias*: I haven't said it explicitly, even though I touched upon it several times: it [physics] has been an extreme comfort to me. This interest has been a great comfort to me in all the times that I've been ill; to focus on this interest, it requires energy, it's something difficult, then you can't think about all that and be troubled at the same time. It's rather impossible. Plus there is something almost religious about thinking about nature. And therefore, it has been a constant recurring … a refuge for me too.

Importantly, the engagement with the physics discipline is not portrayed as 'easy', but instead quite challenging. However, for Tobias the challenges provided by conceptual physics were not deterring, it was rather something that made the discipline absorbing and, consequently, a refuge when thoughts were spinning too fast. In his story, the intellectually challenging nature of physics is in

itself salutogenic, something he can occupy his brain with to deflect intrusive thoughts (Singh et al., 2020). Physics learning offered a sense of serenity, a low-affective, positively valenced state, in the absence of the negative effects from ruminating. In a similar vein, Tina speaks about managing depression from the aftermath of an abusive relationship: 'I got out of there and I got … pretty soon after that I got depressed, and then the psychologist very kindly said that "you get depression because the brain gets a shock"'. Guided by therapy and previous life experiences, she turned to walks in the forest and to science to re-regulate her brain. The focus was shifted from the scattered self and everyday life to resonant experiences of the immovability of the world of matter and its beauty (for related trauma-recovery approach, see e.g. Perrier & Nsengiyumva, 2003).

Third, the potential of physics, its epistemic characteristics, for providing well-being by stability is addressed from another perspective. Tina, Tobias and Kamal have all in various ways received recognition and praise for their involvement in creative arts. In the cases of Tobias and Kamal, they have had short, but successful, professional careers, and they had both also been recognized as being creative in school. Still, both Tobias and Kamal were dissatisfied with their professional careers. Kamal hopes for the objectivity and predictability of physics knowledge to have an impact on how his practices and achievements in the discipline are evaluated. In his previous career he was continuously struggling with feelings of unease related to not knowing what was perceived as meaningful for the audience:

> *Kamal*: When you are [doing art], it ought to be innovative and creative and so on … then there's no one who can tell me how to be creative in a real way, and if it is meaningful for an audience; it's me alone who can decide. And those kinds of thoughts that tormented me, extremely much – How do I know if this is meaningful? – those questions – the search for What am I supposed to do here? What is the purpose of this? – in the context of science, I find it very meaningful, dealing with tasks for which there are no given solutions.

In contrast, taking steps towards engaging in physics, a long-standing point of stability for him, at a higher educational level allowed him to experience a soundness and dependability that contributed to his mental well-being, not claiming that engagement with physics was healing in itself.

Last, for Tina, university physics education offered healing by being treated with dignity. Tina's school years were characterized by outsideness and harassment, and she experienced that the only thing she received acclaim for was her beautiful singing voice. In contrast to Tobias and Kamal, who found communities in the creative arts, albeit ones they in retrospect are highly critical of, Tina's singing voice rather set her apart from her peers. This further contributed to her feeling of being mis-recognized (e.g. Avraamidou, 2022) and intellectually under-stimulated. In physics, she experiences that her intellectual capacity is made use of and she is given opportunities to reach her full potential. Additionally, she expresses that in higher education physics, she can truly be herself:

> *Tina*: And it could also be something that has developed during this year, because I've realized that even here I'm not like everyone else. And I mean, here is still like the nerds' … the muppets' nest. It really is. And yet one really feels at home because it's okay to just … No one cares if you're sitting upside-down on the armchair if that is what you need at the moment. That's totally fine. […] You get to be yourself, kind of, and that's fine.

In this sense, physics is also perceived as a resonant space because she finds physics students to be tolerant and accepting of oddness (cf. Avraamidou, 2022).

To summarize, physics was experienced as a sphere that promoted well-being in four different ways by the interviewees: the discipline provided a sense of meaningfulness (all three), a mental anchoring (Tobias, Tina), was perceived as less arbitrary than the arts (Tobias, Kamal), and recognized for rewarding intellect over social conformity (Tina). Thus, while connecting with physics can make transcendental experiences of connecting with something greater than oneself possible, it is also a space that allows for individuality because of its focus on non-human matter. Importantly, the salutogenic experiences from physics as a resonant sphere are expressed by our interviewees in

contrast to experiences of alienation and largely related to informal learning contexts and adult education.

Choosing university physics as an act of emancipation

The students' trajectory towards higher education is told as personal stories about a 'search for a different way of relating to the world' (Rosa, 2019, p. 27) and a quest for a good life. Here, we turn to the parts of the stories that are told about their agentic movements for life transformation, with attention to the shifts in their relation to formal science education.

The deficiency of resonant experiences and achievements in school science had implications for their late arrival to science. In spite of a prevailing interest in science, studying science had previously felt academically unattainable for Tina and Tobias. Although recognized as intelligent and capable, Tobias related to physics as a love from afar, dismissing a professional career in physics because of difficulties to concentrate:

> *Tobias*: Yeah, because I have an older brother and I spent time with him and his friends. One of them actually works [at University], he tried to talk me into 'choosing the science program' as I enjoy physics so much. But I felt that 'I don't have the capacity, I can't. I'm not a math person and above all … I … lack the ability to concentrate that allows me to think that way'. I'm very clever, and always believed I was. There's nothing wrong with my capacity in that regard, it's about the capacity to direct it, to concentrate on something. […] So, I reckoned, 'I'll never really understand physics. I'll only have a decent understanding and find it fun'.

For Kamal, a science trajectory was somewhat of a non-issue as he was oriented towards a career in arts, and his decision to focus whole-heartedly on physics developed in adult education. All three students acknowledged the importance of adult education beyond accumulation of required credentials and content knowledge. The folk high schools and 'the foundation year' are described as friendly academic spaces that allowed for reciprocal and explorative conversations, and for self-transformation by trying their 'science wings' (see also Bernhard & Andersson, 2017). Though their relationship with school science was mute, adult education allowed them to develop resonant relations to school materials, which strengthened their self-efficacy for pursuing academic studies. With this, new horizontal and diagonal resonant axes were established and made plausible.

As latecomers to science, they can all be said to not only 'opt in to physics', but also 'opt out of' another career and/or way of living. In their stories, a sense of alienation with the lives they lived prior to the decision to study higher education physics is foregrounded. In what he describes as a spontaneous decision, Tobias applied for an adult education program, that would make him eligible for higher education physics studies, to break away from a business he describes himself as 'disgusted' by:

> *Tobias*: 'Ugh, I have to break free, I got to do something else'. So it was an evening among others, and I just – without saying anything – filled in the application for the preparatory year. Because I … I guess I had been chewing on it for a while.

Tobias and Kamal both had successful professional careers, but felt increasingly alienated with the 'shallowness' of the business (Tobias) or precariousness and its perceived 'arbitrariness' (Kamal). Kamal describes a growing distrust to the promise of the 'cool' creative lifestyle in circles with 'legit people'. In contrast, he had enjoyed his part-time job as an after-school teacher more: 'it paid so damn much more, made me much happier somehow'. For Tina, the situation was a different one, where she felt trapped in a manual labour job, but also misrecognized by teachers, a previous partner and herself, as someone not capable of intellectually challenging tasks. She describes facing a breaking point:

> *Tina*: It sounds very strange to people, but I have lived my whole life doing so many things I didn't want to do and being who I didn't want to be. And I had a job where I realized that I can't handle more than about five weeks, or I'll go into depression of some sort because I get so under-stimulated […]

> [Speaking to herself about the HE choice] 'Either you'll live on social benefits and never work again in your whole life, and then you cannot keep your house. Or you may have a job and live on antidepressants for the rest of your life. Or you can leave it and have a life where you don't have to take antidepressants for the rest of your life to be able to live.' And my daughter can have a good mother, a whole mother.

Tina illustrates the choice between following her known path or enrolling in higher education as a choice between a life aided by antidepressants or guided by her own roadmap of needs and desires. The students describe exiting an alienating work-life, that is closing off the relation to themselves.

However, in their stories it is clear that a sense of alienation was not enough in order to leave an, ostensibly secure and established, everyday life. An inclination to accept the risks involved in breaking up was emphasized as well as having the capacity to do so. When Tobias found a treatment that made it possible for him to properly concentrate, another way of living came within reach. As such, choosing physics as a career path was for him also choosing a path that helped to keep his mental health issues in check and where traits associated with his mental illness is not celebrated, in contrast to his previous career:

> *Tobias*: I just felt like 'I do not really know if I have ever challenged myself intellectually, if I have really done that actually.' And I had to have a lot of conversations with my brother about that, 'Do you even think I can learn the math that you do?' And he said that 'No problems, it's just that you will have to make an effort'. And I didn't really believe him. But then I took the science preparation program when I decided to like 'I'm gonna have a go'; that was last year. So I decided that I'm going to do the preparatory year and if that works out, then I'm going to have a go at changing careers.

Daring to go after a dream of studying physics can be seen as emancipatory, but not only in the sense of breaking loose from alienating careers. For all three students, it was also an emancipation of the mind; physics offered intellectual challenges of a kind previously unexperienced by them. Kamal said: 'I wanted to try something new. And as I think of it, I want to see where the limits of my brain are.' Still, for both Tobias and Kamal this does not fundamentally break with how they have previously been perceived and perceived themselves. As previously described, Kamal's strong identification with the arts made it a non-issue whether he was capable of studying physics or not. Tobias had identified as intelligent since childhood, and also built relationships with people who recognized him as scientifically minded, albeit not within the frame of formal schooling. For Tina, describing an urge to recompense for mistreatment, the story is a different one, aligning with Fleming's (2016) report on recognition as the salient motivation for adult students' engagement in higher education. Tina's schooling was characterized by harassment and she did not do well in school physics.

In the school years, Tina thus cultivated an out-of-school interest in physics and astronomy, but was never recognized by any teachers as a student with such interests or inclinations. For her, doing science in different adult education programs and eventually also in higher education, became a way of proving her school teachers and classmates wrong. As such, the higher education physics studies function as emancipation from a narrowly defined position during schooling. But the emancipation goes beyond this. She is cultivating the boundaries and trust in herself that was damaged from the abusive relationship, and her returning to studying as an adult is a turning-point for inviting joy in life and for transcending previous constraints and former identifications. University studies in general, but also physics studies in particular, as a discipline that is perceived as particularly intellectually challenging, becomes important for regaining self-worth:

> *Tina*: [W]hen I took this science course, then I made a deal with myself – because I was still convinced that I was worthless in everything – and so I said 'Yeah, but okay, if I do well on the chemistry test, then I will apply for a science preparation program.'

For Tobias, Tina and Kamal the decision on higher education physics was a turning-point – an act of renewal, of leaving an established, but in some senses unsatisfactory, life behind and seeking

emancipation. As such, they were taking material, intellectual and emotional risks, aiming for a seemingly out-of-reach-self, one that embodied greater autonomy and stable resonant relationships with parts of the world to which they felt affiliation.

Discussion

Why should young people engage in science? This question is often overshadowed in science education, where 'how' and 'for whom' dominate research endeavours. Young et al. (2015), in their popular textbook for university students, provide two key answers about physics: it is 'one of the most fundamental' (p. 1) gateways to a wide range of knowledge, and the learning process itself is both demanding and gratifying: 'You will come to see physics as a towering achievement of the human intellect in its quest to understand our world and ourselves.' (p. 1). On a societal level, science education is often justified by its utility for technological and economic advancement as well as its role in enabling active participation in contemporary society. Indeed, scientific mastery is a potent resource for reinforced control and access to the world, such as optimizing production and consumption (Rosa, 2020). Yet, similar to Young and Freedman's second argument, people also engage with science for affective and aesthetic reasons, whether by disposition or acquired taste.

Our study, based on interviews focusing the question of 'why choose physics', demonstrates a complex interplay of push and pull factors that motivate individuals to commit to physics later in life. Similar to findings on mature first-generation students in higher education (O'Shea et al., 2024), motivations included restoration from misrecognition (especially Tina), seeking a richer, more emotionally and financially stable life, and a deep passion for the subject (all three). As noted by Jackson and Seiler's (2013) study, academic recognition and success in science courses in adult education created momentum for our latecomers' trajectories towards university physics education. While these previous studies provide valuable insights into how science careers are made possible, we argue for the gains in exploring what science can make possible in people's lives. Conceptualizing students' science experiences though the lens of Bildung – utilizing the theory of resonance – offers new insights into how science 'add to our understanding of what it means to be a human being' (Nicolaisen et al., 2023, p. 221), influencing individuation processes and participation in the world.

Nicolaisen et al. (2023) argue that while the sociological questions of 'for whom' (e.g. research on *science identity* and *science capital*) are crucial, they are insufficient if we consider science as part of a life well-lived. Instead, we should ask how unequal access to science education enables and hinders access to agentic, meaningful engagement with the world. The examples from our interviewees' lives, conceptualized as *resonance* and *alienation*, provide a starting point for reconsidering what engagement with science can contribute with in the lives of both young people and adults.

Why science? New answers with resonance

Experiencing the world and oneself differently

The interviewees valued physics for transforming their relationship with the world – in exploring the intricacies, and entirety of the Earth and the Universe. The laws of physics enriched their everyday lives and accentuated their surroundings as fascinating and beautiful, designating human beings as insignificant, yet integrated, parts of 'complex natural systems' (Cuzzolino, 2021, p. 702). Beyond school science, they experienced themselves as capable of reasoning and resilience when engaging in science practices, as someone who found pleasure in tackling complex, significant issues. While influenced by prevailing narratives about the seriousness and demands of science, their stories suggest that grappling with epistemic and ontic questions of physics can be helpful in approaching existential matters and crucial for self-realization. In summary, learning reshapes our perception and self.

Cultivate resonant relationships

Our findings indicate that a resonance relationship with physics can support formation of other relationships. The obvious example is communities that form around scientific interest, such as amateur astronomy organizations. Pleasurable engagement in physics can, as recognized by our interviewees, reinforce the willingness and capacity to develop more relationships both within the science domain and with the world at large. Science engagement is formed within a complex web of human, material, and ideational relationships. The trajectories for latecomers in science may be shaped by mute relationships with science (school science for all three), and sufficient resonance relationships in other academic (arts in Kamal and Tobias) and social (e.g. Tina's first romantic relationship) spheres (see also Jackson & Seiler, 2013). The interviewees' relationships with family members, friends, and teachers had both pushed (e.g. Tina's abusive partner) and pulled (e.g. Tobias's brother and Kamal's partner) them towards science education. Our analysis demonstrates how a love for physics can benefit from epistemic practices that offer 'rigour and stability' (Holmegaard et al., 2014, p. 212), and reinforced belief in 'the idea of an *accommodating*, *responsive* world' (Rosa, 2019, p. 260).

Well-being

Tobias, Tina, and Kamal, as latecomers to science, reported improved well-being from promising professional prospects and emancipation. Moreover, similar to Perrier and Nsengiyumva (2003) findings from a study of traumatized children, science supported well-being by directing our interviewees' attention to queries into non-human matters. Though we recognize the challenges of pursuing science education during hardship (Jackson & Seiler, 2013), especially Tobias and Tina were helped to a state of serenity, of feeling connected and grounded. As Alsop and Watts (2003, p. 1046) suggest, 'it is the very predictability, the safety offered by science that appears to build a platform to restore an attitude towards the world'. We therefore suggest that the laws of physics can serve as *beautiful boundaries*, offering a promise of solace in precarious lives, especially for people facing chaos and mental health challenges. As outlined in the previous sections, although physics seeks reified understandings of the world, which may promote alienated relations, it offered structure and experiences that, in the lives of our interviewees, enabled well-being from multiple axes of resonance – from relations to engaged peers and teachers and materials for learning with the concepts of physics, to aesthetic and transcendent experiences of being connected to the world (Thurfjell et al., 2019). That is, engagement in physics can contribute to well-being.

Rethinking science education with resonance and slow science education

With Rosa, we can also shift the focus from how education can aid students in forming vibrating relationships with science to how (science) education can cultivate students' resonant relationships with the world (#2), by seeing the world and oneself differently (#1). Rather than making science/physics engagement the end goal, the greater aim of (science) education becomes to enable lives well lived (#3). From this perspective, a critique of the techno-scientific rationale of privileging the objective, abstract and contextless can still lead us as science educators to teach a more context-rich science, allowing students to relate it to their everyday experiences (e.g. personalizing and localizing in the science capital teaching approach, see Nag Chowdhuri et al., 2023; for university science education, see Jackson & Seiler, 2013).

With Rosa's framework, resonant relationships with the world can also emerge as science provides an ontologically stable structure when relating with the world (#2–3). This, however, requires a slow-paced education environment, where students are given space to explore how they can engage in science by 'creating opportunities for authentic inquiry and encouraging metacognitive' (Cuzzolino, 2021, p. 700) or existential reflections. A *slow science education* inspired by the philosopher of science Isabelle Stengers' slow science, provides an alternative to the escalatory logic of modernity, so far usually accelerated by science, that contribute to a crisis of resonance in late-

modern societies (Rosa, 2020). Taking resonance into account in science learning would furthermore involve taking cues from 'resonanzpädagogik' to create a *didactics of resonance* ('resonanzdidaktik') to further the relationship between teacher, student and science as a 'triangle of resonance' (Rosa, 2019, p. 243).

We propose that education should prioritize attentiveness to a diverse range of 'whys', allowing for resonant relationships between student and the world to emerge within friendly and respectful learning spaces. In science education, this shifts teaching from student-oriented to relation-oriented. Vertical, horizontal and diagonal axes as a didactical model help educators address multiple dimensions of individual's relationships. That is, multiple axes of resonance in the physics sphere – not always equally strong, but interwoven – can foster well-being and make new engagements with the world possible.

Notes

1. In Sweden, free supplementary education routes include the 'foundation year in natural science' (naturvetenskapligt basår) at university, municipal adult education (komvux), and folk high schools (folkhögskola). These pathways prepare students for tertiary-level science studies, and the university foundation year ensure admission to science programs. Municipal adult education and folk high schools offer flexible secondary education, with folk high schools emphasizing a Bildung-oriented approach focused on fostering 'democratic values and active citizenship' (Bernhard & Andersson, 2017, p. 89), self-development, and increasing access to higher education.
2. This is a verbatim transcription but organized into stanzas to better capture the rhythm of the spoken words.

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