SYMPOSIUM - Equipping Teachers to Support Student Reasoning about Everyday and Complex Phenomena

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Abstract. This symposium is proposed by the GIREP Thematic Group "Physics Preparation of Teachers in Grades K-6" and consists of a discussion of two approaches to teacher education and professional development in elementary school grades, as well as secondary school grades. The first contribution illustrates how imaginative understanding of forces of nature and their interactions provides a pathway to complexity in natural systems. The last two contributions describe research-based efforts to prepare teachers to support explanations of complex phenomena associated with climate change.

Introduction to the topics for the symposium discussion

Preparing teachers to help students in grades K-6 to start to develop a scientific outlook toward natural phenomena requires attending to several factors. On one hand, students are at developmental stages that can be especially well leveraged through the use of metaphor and analogy, which, according to Lakoff and Johnson [1], fund our abstract concept development. On the other, intuitive ideas induced from sensorimotor experiences, and the "Ohm's Law" phenomenological primitive (p-prim) "Increased cause produces increased effect" [2] fail in situations where small causes can produce large effects, such as in climate change. Furthermore, to address complex socioscientific issues, developing a particular teacher identity is an additional factor to consider. In this symposium, we bring these approaches in contact.

In the first paper, "Forces of Nature and complex systems" by Federico Corni and Hans Fuchs, the authors present a well-developed approach to teacher education [3-5], which capitalizes on the affordances of embodied cognition and leverages semiotics to help teachers (and their students) develop meaning of forces-of-nature phenomena. They show how models of interactions of forces of nature can be used for approaching complexity in natural systems.

The second paper, "Science Teachers' Integrated STEM Teaching Material on Climate Change" by Emily Michailidi et al., explores an integrated STEM approach to address climate change challenges [6], examining teaching materials developed by science teachers in a collaborative community of practice [7]. Findings reveal a varied emphasis on sustainability competencies [8] among teachers as well as specific challenges faced regarding STEM disciplines integration [9].

The third paper, "Secondary pre-service teachers' perspectives on Climate Change as a Complex System: The Role of Identity" by Chara Bitsaki et al., investigates the development of Teacher Identity for Climate Change Education utilizing the Greencomp framework for sustainability competencies [10-13]. The authors argue that the interdisciplinary approach of complex systems [14] contributes to building pre-service teachers' sustainability competencies for a deeper understanding of the multifaceted aspects of Climate Change.

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Forces of Nature and Complexity

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Abstract. We describe the characteristics of Forces of Nature (FoN) such as Wind, Sunlight, Water, Heat, Substances, and Gravity, that arise as primary perceptual units in the ways in which humans experience the world. When FoN interact in chains and in parallel, and create (nonlinear) feedback structures, complex behavior may arise in dynamical systems. Loss of sea ice caused by the interactions of Light, Heat, and Substances—aided by changes in the material environment caused by these very interactions—may serve as an example for how complex systems can be modeled and understood.

Forces of Nature

Human-nature interactions are an issue of great concern, not least because of climate change and threats to biological diversity. Systems allowing for such interactions are inherently complex, raising the question of how to deal with them in education. Restricting our attention to finding complexity in physical processes in nature and machines may make the challenge less daunting, especially for early education. The reason for this is simple: We can recognize Forces of Nature such as Wind, Sunlight, Water, Heat, Substances, Motion, and Gravity as the causal agents for simple to complex behavior in natural and technical settings; and since Forces of Nature appear in primary experiencing, and can be understood imaginatively, we may be able to design pedagogy leading to a first understanding of complexity [1-3].

A Force such as Wind arises as a causal entity, first, in direct physical experiencing, then in the stories we tell about how it acts and what this means for nature and its inhabitants. The imagery that arises in our mind is that of a forceful figure, an agent, that can activate other Forces such as Electricity in a wind turbine or the wavelike flow of Motion through the ocean over great distances leading, finally, to the erosion of beaches and the production of Heat. Where Electricity, Motion, and Heat have been patients, they have become agents through the power of Wind.

In its interaction with Electricity, mediated by a wind turbine, Wind arrives in an intense (tensed) state, and it will leave the place of interaction substantially relaxed or weakened. Electricity, on the other hand, will have been "activated," meaning that its tension has been raised, and it has been made to flow to a place where it, in turn, can act as an agent. We recognize a Force to be (more or less) intense and to be (more or less) extended (spatially, and sometimes temporally), factors which, conjunctly, determine its power.

Complexity arising in the interaction of Forces of Nature

In this short narrative, the Forces of Wind, Electricity, Motion, and Heat appear as figures upon a scene or background formed by physical objects such as a wind turbine, the water of the oceans, or the sand and rocks of a beach. While, at first, these objects appear as the inert ground or stage upon which the drama of Forces unfolds, we know that this ground is affected by the activity of Forces. Over time, this leads to a change of scenery for the agents, which will change how exactly they can act and interact. We shall see that interactions of Forces, affecting and being affected by changes of a material scenery, can be the source of complex behavior in dynamical systems.

Consider the example of processes currently leading to the loss of arctic sea ice. In a narrow sense, this is not an example of complexity, but it tells us about an interesting dynamical phenomenon; and, as a part of our planet, it will add to the complexity of that system. The phenomenon alluded to is that of (positive) feedback. If it is absorbed, Sunlight activates Heat by producing it, raising its tension. Heat becomes an agent in the melting of Ice. While Ice is a Force whose extension (amount) is changing (a chemical process), it is at the same time part of the physical scenery which will be changing—there will be more water surface which, in contrast to the ice, absorbs Light. More Heat will be produced, leading to faster destruction of Ice, letting Light and Heat become more powerful in the arctic, and so on.

Telling stories of Forces acting and interacting: Roads to pedagogy

We have designed an example of a moderately complex natural-technical system along with concrete pedagogy allowing young learners to approach it. The system is one where we let Sunlight activate Electricity which, in turn, powers a ventilator—it is summer, it is hot, and we are seeking relief from Heat. This constitutes a short chain created by interactions of Forces. Note that, in a parallel chain, Sunlight will evaporate Water from a nearby body of water, maybe aided by the Wind produced by the ventilator (this leads to an easily visualized case of feedback). Interacting with Gravity, Vapor will rise and form clouds—this changes the natural scenery, the ground upon which the Forces are active. Sunlight might now be blocked, interrupting the operation of the ventilator—note an element of complexity that makes it hard to predict when a cloud will block the sun.

We can create an engaging natural-language story that lets the characteristics of Forces and their interactions arise in our mind, ready for our imagination to engage with the situation [4]. Here, we present an example of storytelling that uses bodily mimesis: we can create a Forces-of-Nature Theater (FoN-T) performance in which learners represent Forces and their forceful interactions [5]. There will be groups of students representing Light, Heat, Electricity, Wind, and Vapor. We use props for modeling the environment (here, essentially clouds forming spontaneously, blocking Light). An additional prop may be used for representing energy: we may introduce confetti or some similar mass-like stuff for symbolizing energy that is carried by agents and "handed" to patients in their interaction, making the patients new agents. Note that, when some confetti drop to the floor during the interaction of two groups of actors, this can be seen as representing dissipation, because of which Heat is produced [6].

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Science Teachers' Integrated STEM Teaching Material on Climate Change

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Abstract. Addressing the challenges of climate change requires an integrated STEM approach that goes beyond traditional discipline boundaries. This study delves into the integrated STEM teaching materials on climate change developed by 8 science teachers, collaborating in a community of practice. The teaching modules show a variety of emphasis on sustainability competencies, with physics teachers stressing systems thinking and anticipatory competency and primary teachers focusing normative and strategic competence. Despite initial obstacles, in-service teachers successfully integrate STEM disciplines, demonstrating the potential for collaborative design teams to support professional growth in climate change teaching.

Introduction

The complexity of climate change and the uncertainty of the ways of response to these challenges demand not only the understanding of the underlying scientific principles but also a deeper understanding of the nature of the problem, debates around the appropriate pathways forward and the development of sustainability competences [1]. Such scientific understanding and competences cannot be achieved by a strictly single-disciplinary teaching approach that targets solely cognitive objectives nor by a more generalist sustainability education approach. It demands an integrated STEM teaching approach where various S-T-E-M disciplines intersect, illuminating the links and interweaving between science, mathematics, technology [2]. This interdisciplinary STEM approach, in order to be effectively enacted by science teachers, calls for a transcendence of their original disciplinary teacher identities and an alignment with a more integrated STEM teacher identity. Particularly, science teachers have to be prepared to design impactful integrated STEM learning environments that reveal the multiple facets of the phenomenon and enhance students' related competences. However recent research reveals that both primary and secondary education science teachers face difficulties in embracing an integrated STEM approach [3], therefore suitable professional development programs for science teachers need to be designed. Teachers' participation in collaborative design teams has emerged as a particularly effective way of professional development mainly due to the collective learning and exchange of good practices that take place in these environments [4]. Impelled by the abovementioned considerations, the aim of the present study is to give an insight on the teaching material in-service science teachers develop as a result of their participation in a community of practice directed towards scaffolding the development of their STEM teacher identity for climate education.

Theoretical framework & research questions

Climate literacy refers to the ability to understand and engage with climate science, its implications, and the actions required to address climate change. To be considered climate literate, one would possess a combination of knowledge, skills, and attitudes, which are met in the literature with the term *sustainability competences*. These competences can be organised under 5 key axes: systems-thinking; anticipatory competency; normative competency; strategic competency; and interpersonal competency [1]. As regards STEM integration, the inter-connection of S-T-E-M disciplines and the incorporation of real-world situations is considered by science teachers as a demanding process while they don’t tend to give equal emphasis to all disciplines in their STEM lessons [3]. Therefore, in this study we aim to explore teaching material developed by in-service science teachers in terms of incorporating sustainability competences and interconnections among S-T-E-M disciplines. The research questions that drive our study are: (i) How do in-service science teachers incorporate sustainability competences in their teaching material on climate change? (ii) How do in-service science teachers integrate S-T-E-M disciplines in their teaching material on climate change?

Methods

In the context of our study, 8 in-service science teachers (4 primary education teachers and 4 physics teachers) formed a community of practice in collaboration with climate science researchers, and science and mathematics education researchers with a shared goal to develop integrated STEM teaching material on climate change. Through a series of face-to-face and distance workshops, teachers were oriented on contemporary theoretical approaches pertinent to the scientific topic of climate change, the interdisciplinary STEM teaching approach, and sustainability competences development by expert research team members. Afterwards, science teachers, with the support of the community of practice, designed and developed STEM teaching material on climate change which was then piloted in their classrooms. Data were drawn from the lesson plans and worksheets developed by the teachers and additionally from the audio recordings of the community of practice meetings.

Findings and Conclusion

A total of 8 teaching modules were developed from the above process. From the analysis of the teachers' lesson plans, it emerges that with regard to the sustainability competences, the ones that appeared more frequently in physics teachers’ materials are systems thinking and anticipatory competency, while primary teachers focused mostly on normative and strategic competency. In terms of STEM disciplines integration, in-service physics teachers originally faced difficulties in integrating aspects of math and engineering however these were outbalanced by the contribution of researchers. Primary education teachers, on the other hand, were more fluent on placing equal emphasis on all four disciplines, but needed support in giving prominence to the interconnections among them.

From the above, it derives that in-service science teachers managed to integrate various sustainability competences in their teaching material, as well as to integrate all S-T-E-M disciplines quite effectively. Therefore, their participation in the practice composed a supportive context, rich in resources for their professional development regarding climate change education.

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Secondary pre-service teachers' perspectives on Climate Change as a complex system: the role of Identity

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Abstract. This study explores the development of pre-service teachers' Climate Change Teacher Identity to enhance sustainability competencies in Teacher Education. A pilot implementation took place with 12 secondary pre-service teachers engaged in activities focused on complexity concepts related to climate change. Qualitative content analysis of student conversations reveals that disciplinary background influences perceptions of complexity as well as that interdisciplinary approaches to complex systems examples contribute to a deeper understanding of the multifaceted aspects of Climate Change. This research highlights the significance of teacher identity in shaping effective climate change education.

Introduction

Addressing the challenges of the climate crisis requires fostering climate literacy among students to empower them as future citizens capable of making informed decisions. The European framework "GreenComp" outlines essential competencies for climate-literate citizens (Bianchi et al., 2022). Climate change complexity, encompassing scientific and social dimensions, necessitates a holistic approach to teaching. Nevertheless, variations in pre-service teachers' familiarity with scientific content impact their confidence and their ability to transcend disciplinary boundaries (Ryu et al., 2019). Therefore, effectively implementing such instruction requires well-prepared teachers, highlighting the importance of ongoing professional development.

A way to study teachers' professional development is through the lens of teacher identity. Through the development of a Climate Change Teacher Identity, pre-service teachers can increase their climate change content knowledge, while enhancing their ability to embody this knowledge with their values and beliefs. For the development of climate change teacher identity, it is essential to take into consideration teachers' science identity since this identity interacts with their professional identity (Avraamidou, 2014). Thus, the utilization of Carlon and Johnson (2007) framework for science identity provides important insights regarding a) Competence: Content knowledge and understanding of Climate Change b) Performance: Social performances of relevant to climate change content and practices, and c) Recognition: self-recognition and recognition from the others.

Hence, this study focuses on developing pre-service teachers' professional identity for climate change education (climate change teacher identity) as a means for the teachers to build the necessary sustainability competencies (knowledge, skills, and attitudes) to be able to teach the topic of climate change holistically.

The research questions that guide this investigation are the following:

1. How do secondary pre-service teachers with different backgrounds perceive and engage with concepts of complexity in the context of climate change education?
2. What specific aspects of the program activities contribute to shifts in pre-service teachers' identity towards a holistic perspective on climate change?

Methods

To address these research questions, we designed a teacher education program focused on the development of pre-service teachers' Climate Change Teacher Identity to be able to enhance students' building of sustainability competencies. In this study, we are going to present the structure of the designed pre-service teacher education program as well as a pilot implementation of the activities that were designed to introduce the pre-service teachers to complexity. During these activities, 12 secondary pre-service teachers with a background in physics, mathematics, and computer science, were introduced to concepts of complexity such as i) sensitivity to the initial conditions, ii) order in chaos, iii) critical states, and iv) self-organization (Stavrou & Duit, 2014) since those concepts play a significant role in enforcing understanding on Climate Change content. The implementation took place in an international summer school with students from Italy, Spain, France, and Greece.

Data were collected through audio recordings from the summer school implementation, which contained open student-student and student-instructor conversations. Due to the exploratory nature of this study, we used qualitative content analysis methods. Researchers examined the data derived from the implementation, to develop a category system based on Carlon & Johnson (2007) theoretical framework about science identity, and more specifically in competence/performance of the pre-service teachers regarding complexity. In addition, we investigate the events during the implementation that contributed to shifts in pre-service teachers' identity.

Results and Conclusions

The analysis of the pilot implementation is still ongoing; therefore, the primary results of the analysis reveal significant differences in the perception of complexity among pre-service teachers with different disciplinary backgrounds. Moreover, identify the contribution of interdisciplinary approaches to a deeper understanding of the complexity of climate change. Analyzing the pre-service teachers' conversations provided us with the disciplinary challenges they faced such as the serial perception of the phenomena by computer scientists and the cause-effect relationships by the physicists. Moreover, we were able to identify the contribution of examples of complex systems in science as important aspects to enhance their understanding of the social and financial complexities of climate change.

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