Embracing Complexity – Computational Essays in Fostering Authentic Scientific Reasoning

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Abstract. Creating a scientifically literate population requires insight into how scientific thought is developed and put into practice. Computational essays can provide structural support for acquiring such argumentation skills through data-based reasoning while promoting the students' epistemic agency. With open data, this method can provide a valuable, authentic and easily accessible experience of scientific work in modern and varied contexts. We present a pilot look at a pre-service teacher course combining field work, expert lectures and data analysis, exploring how the medium of computational essays can be used to foster a deeper understanding of empirical sciences.

Introduction – computational essays and open data

Computational essays are a recent development that combine traditional long-form essays with live, executable code and data analysis into one easily shared document. Such methods have great potential, yet are not widely used for educational purposes [1]. Computational essays are a powerful tool for exploring open data with pre-university students and pre-service teachers in an authentic fashion that promotes their epistemic agency in ways that correspond with the stated goals of many school curricula (such as learning algorithmic thinking or cross-disciplinary problem solving in the digital era). This combination has several benefits for fostering desired aspects of scientific and computational literacy in students [2]. Open data provides access to recent and topical information on modern questions and methods in scientific research, increasing the authenticity of the educational activities and promoting better understanding of the work that goes into data presentations that they encounter in their daily lives. Computational essays provide structure to this endeavour, forcing the students to explicate their thinking and arguments in a manner that is understandable by both humans and computers alike. Our Open Data & Education project at Helsinki Institute of Physics works with secondary school teachers and teacher education to develop and field such tools, covering a wide variety of topics from particle physics to climate data and beyond.

In this presentation, we focus on the quality of structural elements in scientific argumentation, as found in educational computational essays performed with open data by pre-service science teachers. Can our proposed rubric discern differences between them?

Theoretical framework – coherency in reasoning

Learning to reason and to make compelling evidence-based arguments can be seen as one of the central goals of science education, for how can a person participate in the creation of new knowledge without the skills to do so [3]? Teaching these skills is often only implicitly present in school and studies on pre-service teachers at university level have found their argumentation in open tasks to fall towards incoherence unless scaffolded [4]. Computational essays offer a suitable platform for such purposes, as by their very nature the students cannot get very far in their assignments without forming at least somewhat coherent chains of thought and as writing a computational essay is an act of scientific inquiry in itself, the medium inevitably forces authentic

epistemic action on the student through its mere inclusion in the task. Using a four-step model for coherent argumentation (Background – Assertions – Inferences – Conclusions [4]), we propose a qualitative analysis rubric for differentiating the quality of argumentation at each step. In this pilot, it was applied to works produced by a small group of pre-service teachers on a field course to an active multidisciplinary research station (SMEAR-II, Hyytiälä). The rubric was used individually by two physics education professionals to find argumentative quality differences in the computational essays produced, with an agreement rate of over 95%. The rubric worked reliably and will guide us in improving the next iteration of the course in 2024. As quality of argumentation often depends on the depth of previous subject knowledge possessed, and learning to argue in depth simultaneously consists of learning the subject as well, improving the perceived relevance of the investigated topics is important. For this, we emphasised certain aspects of authenticity in course design, such as content related perspectives or insight into the process of experimental research to engage the participants from multiple angles [5].

Praxis – programming with purpose

Feedback gathered from hundreds of secondary school students between 2016-2024 consistently indicates that the "real world connection" of open data feels meaningful to them (95+ %), they have learned more about scientific methods (95+ %), computation suits the topic (95 %) and they would like to do more of this in school (75+ %). This positive reception remains largely untapped. Supporting teachers, both in- and pre-service, to take up such materials can be argued to be an important step in meaningful digitalization of education while improving their general argumentative skills necessary for good teaching and assessment. Nine pre-service teachers participated on our field course to an active research station (SMEAR-II, Hyytiälä) in November 2023, met the experts working therein and wrote computational essays on openly available data from the very same experiments. While their subject knowledge content did not necessarily take any dramatic leaps forward in such a short time, the format appears to support cohesive argumentation and very open-ended approaches to the inquiry itself. Analyzing the essays, three groups of varying argumentative capacity emerged. In particular, the participants were proficient in formulating research questions and data-based reasoning, but split in their abilities to communicate their inquiry process or demonstrating ownership of the research process.

References

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