Polyphonic STE(A)M and the role of Physics

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Abstract. We propose a pedagogical ‘model for polyphonic STE(A)M education’. With this model teachers worked a yearlong in a Professional Learning Community. The model made schools think about their choices for STE(A)M and it gave them a ‘language’ to explain their choices. Why should schools do STE(A)M? What is STE(A)M? How and for Whom schools bring STE(A)M into their curriculum? During the course of the PLC, it became gradually clear that single subject matters still play a crucial role in STE(A)M and precisely from this insight the polyphonic model arose. Different viewpoints and inquiry methodologies from single subjects are needed to discover the connections between and across the disciplines. We illustrate this interdisciplinary STE(A)M education model in a few examples where physics plays its role between arts and engineering. It was recognized in our PLC that STE(A)M learning within and across disciplines makes lessons more relevant to learners, as they see how things are related and this also seems to foster creativity and problem solving. This confirms what was found in educational research. By reflecting on their practices, schools rediscovered that, apart from aiming at children with talent for STE(A)M, it is still their duty to give children also ‘STEM for all’ and ‘STEM to explore’ experiences.

1. Introduction
Interdisciplinarity has since long been an issue in education, even before STEM was put on the educational agenda. Based on experiences with a Professional Learning Community (PLC) of teachers, we propose an interdisciplinary pedagogical model for STE(A)M, we call the ‘model for polyphonic STE(A)M education’. This model consists of:

1. An attempt to answer the four questions: STE(A)M Why? What? How? For Whom?
2. A specific model for the What? in which the specificity of each single discipline and the interaction between disciplines both find their place.

It essentially focuses on deepening your discipline through dialogue with other fields. Research tells us that Interdisciplinary learning couples with 21st century skills and competences: creativity, problem solving, collaborative learning... it all seems to benefit from this interdisciplinary dialogue. As a consequence practicing ‘polyphonic STE(A)M’ does a lot more than only deepening your discipline. We will share in this article our experiences with this PLC on STE(A)M and we’ll illustrate the pedagogical meaning of this model with these concrete experiences.

In doing so, we hope to make clear the role of STE(A)M for physics, and the other way around, of physics within STE(A)M. Physics, and more generally the sciences, were found to be a valuable (and often an essential) ‘voice’ in polyphonic STEAM. We will illustrate this in particular by means of two examples that we interweave here and there to illustrate our model: one is the EU-project iMuSciCA, where schools in Belgium, France and Greece practice interdisciplinary learning between physics, music...
and engineering. Another is the EU and Flemish project “Quantum SpinOff” where we learn how fundamental physics, in case Quantum Physics, plays an important role in all kinds of modern (electronic) applications and therefore in a broad spectrum of socially relevant enterprises who work out these applications. Both practices illustrate our polyphonic model for STE(A)M learning.

2. Methodology
The model of ‘polyphonic STE(A)M’ was developed and tested in the framework of a Professional Learning Community: some schools locally in the province of our teacher education institution, formed a STE(A)M Learning Community (called ‘MeerSTEMmig’). Later on this PLC was expanded into a broader network of schools in the whole of Flanders where the model was further worked out (called ‘Vlaams Lerend Netwerk STEM SO’). We will focus here mainly on the experiences of the local STEM community ‘MeerSTEMmig’.

The methodology used was that of a Professional Learning Community (PLC). Its main point is that teachers work around a common goal, here bringing STE(A)M into their classroom and share information and experiences with each other on a regular basis. Our local professional Learning Community MeerSTEMmig shared the same STE(A)M lessons, consisting of new interdisciplinary learning materials developed by the teachers together with a group of teacher educators. Both the teacher educators and the teachers had different backgrounds: physics, math, technology, biology etc. In the local PLC on STE(A)M there were over 30 teachers from 12 different schools. They met each other 3-4 times a year. Within this large group working groups were formed. Each of this working group developed concrete interdisciplinary STE(A)M lesson materials that were tried out consequently in class. The whole group kept on reflecting on general principles of the desired STE(A)M pedagogy. Improvements and additions were made upon these experiences both to the concrete lesson materials as to the general view on the STE(A)M pedagogy. Five teacher educators and researchers of our group supervised the PLC and on teacher’s demand also concretely contributed to lessons as to the common developed interdisciplinary pedagogy.

3. Towards a model for Polyphonic STE(A)M Education
The model for polyphonic STE(A)M education that came out of the PLC shows on the one hand how important it is that different subject matters can interplay and how this play might come into the classroom. On the other hand it gives some first answers to schools and teachers who want to work with STEM in the class. In this sense it gives some directions and will shed some more light on pedagogical questions that will rise when you start with STE(A)M in your school. Why should you do STE(A)M? What is STE(A)M? How and For Whom you will bring STE(A)M? These questions were risen by the teachers themselves in the PLC though these questions can be found as well in some form in pedagogical books and literature [13, 14]. The polyphonic model arose in order to try to answer these questions. We will present here these questions and the answers proposed by this so-called polyphonic model.

3.1. Why?
Many times it has been said that STEM is needed in schools because we need more kids to choose for STEM careers. Of course this is true and we will not deny this societal reason to introduce STEM in schools. Motivating young people for STEM and STEAM remains one important point in the ‘why’ of our model. However, how important such a societal need might be, it can never be the only, nor the main, reason why schools should do STEM. The reason why we need to get involved in STEM is much more simple: it is because STE(A)M is all around us and part of our world and school has the duty to show the world [7].

Look around and you’ll see a lot of interdisciplinary teams. In research institutes, in companies, in art… people of different backgrounds work together in other to discover new findings, to create new solutions. They contribute from their disciplinary insights and skills towards something new, a new creation, a new way of thinking or looking at things.
Education is the point at which we decide whether we love the world enough to assume responsibility for it (H. Arendt)

So the polyphonic model of STE(A)M proposes STE(A)M as an ‘Inter-Esse’ (to be in between). So not so much (though it eventually can be) a product of an individual subjective choice or an individual talent but rather a process to give together significance and meaning to STE(A)M as part of our shared world. Part of the ‘Polyphonic STE(A)M Pedagogical’ model is therefore that we look to the outside world where STE(A)M is present and STE(A)M teams are alive. These STE(A)M people are creative in a STE(A)M world within and across their disciplines.

In the example of Quantum SpinOff the students (of secondary education) contacted a researcher, a technician or an entrepreneur (in a research institution or in a company). They visited this company or research group with the aim to find out what knowledges and skills came together in that research or in that company and they understood these are related to subjects at school. They also discovered for instance that fundamental quantum physics is applied into companies and research groups, in many cases for societally relevant purposes, and that to do this a collaboration between scientists, engineers and technicians is needed. The students were given the opportunity to learn something about the hitherto unknown modern quantum physics and its applications in the real world of STEM. But the task was not only to deepen out some of these insights and skills, but also propose some kind of application with it. This gave interesting interactions between the students and the researcher, the entrepreneur or the technician, but also with the teacher. They learned to relate fundamental insights to modern technology, even though this relation was not so simple. In the last runs of Quantum SpinOff we even asked the classes to create a work of art related to the physics or the application and to express their fascination for the subject studied.

So the polyphonic STE(A)M pedagogy we propose here, mirrors in the class the world outside. We learn students to discover this STE(A)M world by contacting workers, researchers, entrepreneurs, artists… but also by studying the disciplines themselves and their connections (see further under ‘What?’)

STE(A)M is intrinsically significant as a part of our shared world

By doing so, it might be that polyphonic STE(A)M in your school is a bit broader than just focusing on the jobs the society is asking for. So be it. But don’t worry: the gain for society is still there. Researchers confirm that interdisciplinary education fosters creativity, problem solving and collaborative learning. Aren’t that the 21st century skills society is looking for? Interdisciplinarity addresses this creative process across different fields and this fosters creative development [8, 2, 12]. Creativity couples even more when arts is connected to science. [1,3]

3.2. What?

Although it might be surprising that you can deepen the understanding of one discipline by looking at another, the clue seems to be in augmenting the relevance of the subject. The relevance of a specific topic like physics, becomes more clear to students when they see how it fits within a bigger picture. We give you below an example on how we relate physics to music and engineering in iMuSciCA.

The relevance of a specific topic is clearer to students when they understand how it fits within the big picture. [9]

STE(A)M is not about replacing the single subjects by an integrated subject STE(A)M. Some schools in our learning group thought that this might be the ultimate goal of STE(A)M: to make the single subjects superfluous. But STE(A)M doesn’t work without disciplinary thinking and skills, it is about
connecting the subjects, not to forget about them. On the contrary, by deepening them, by making them stronger, one discovers the connections. This process will make every subject touched upon more relevant and this will have a positive effect on student’s motivation.

Musical Analogy to the Polyphonic STEAM Pedagogical Model: Compare it with a polyphonic musical piece. You have separate voices, they stay in their own strength but that doesn’t prevent the emergence of a whole musical piece, on the contrary: all the voices together are necessary and related to each other: they form one coherent piece with intervals, harmonies, consonances and dissonances.

The polyphonic STE(A)M model fosters these connections and important is to make them explicit to the learners too. By making students experience and discover relations between hitherto unrelated subject matters, they become more aware of their learning and the relevance of it. Let students experience a ‘many worlds’ journey through different STEAM fields and let them learn how concepts, skills and even the manner people inquire in those worlds differ. But let them experience that all these different fields say something about the same phenomenon.

Example from iMuSciCA: Students in school learn about waves and superposition in physics and mathematics, they don’t connect this to what they are experiencing in music: melody, timbre or harmony. The same goes for engineering: while performing a task like designing their own instrument, they don’t really are aware that concepts of maths and physics and music are at stake there.

3.3. How?

Many teachers in our STE(A)M PLC reported to have good experiences with an inquiry pedagogical methodology in the class. However, it became gradually clear that teachers from different backgrounds talking about the pedagogical methodology of inquiry, mean slightly different things. Indeed, although inquiry may have some general common characteristics over all the disciplines, it also differs from one subject to another.

We give an example to illustrate the different ways of inquiry in different STEAM-fields (example of iMuSciCA). One important difference consists in the way you start the inquiry. For example, if you let students inquire the phenomenon of ‘timbre’ in music, they can start by a question like ‘Do different instruments sound differently?’ They can listen to instruments playing the same tone. So inquiry in music is about listening, about playing on different instruments, about making music with instruments of different timbre etc. Now when you start looking at timbre from a science point of view, you ask other questions like ‘Why does the sound changes from one instrument to another?’. Then you will inquire what makes the sound change from one instrument to another. You will inquire this by measuring varying intensities of upper tones on different instruments and maybe you succeed in explaining how waves of single harmonics add up with different intensities. You can also look to the phenomenon of timbre from an engineering point of view, than you might ask “How can we design an instrument with these or those upper tones?”. Maybe you use a virtual model of a certain instrument where you can alter the characteristics of the resonating body etc. On the basis of your model, you could then maybe construct one. Therefore not only the starting point differs, but also the way the inquiry is performed. For instance, if you have a ‘creation’ phase, this will differ depending on the discipline: creation in music is creating music, while creating in science is creating a model, a representation that explains something, creating in engineering, is also creating a model, but now with the aim of solving a problem or producing a prototype.
So also inquiry phases differ from one discipline to another, because questions differ and so does the methodology to answer those. Since you need different disciplines in order to let students discover the connections between them [4], different methodologies can be used, appropriate to a specific disciplines.

It turned out in the PLC that this insight was not only pedagogically important, but it might be also relevant to the students themselves: STE(A)M is about doing inquiries from different viewpoints and with different methodologies. Therefore the methodology of STE(A)M is also part of the content itself. Inquiring the same phenomenon from different subject matter viewpoints and with appropriate methodologies in order to find connections and see the bigger picture, that’s what STE(A)M is about, both in school as in the real world. Moreover, research indicates that discovering those connections makes learning more relevant to students, it fosters 21st century skills and it augments creativity especially over borders of subject matter fields [5, 9].

Another issue that came up in the PLC was about the degree of guidance the teacher should give during inquiries. Most teachers had initially the impression that the more open your inquiry was, the better. Although they recognized that in classroom those open inquiries did not always succeed or not always with all students. Why could that be? Research might help here to enlighten the situation a bit: too open inquiries turn out to be rather disadvantageous for students with a weaker background [6]. The consequence of this pedagogical insight seemed to be that teacher guidance at certain points is still needed, moreover is necessary, wherever you see students with weak backgrounds. In other words scaffolding from a good teacher is needed. For open inquiries to succeed it is important to make starting conditions as equal as possible and to equip students with some good starting conditions. Of course we need to find out which are good ways to do that.

3.4. For Whom?

In Flanders, and maybe in other countries too, the STEM-movement in schools was initially focusing a lot on ‘talents for STEM’. Indeed, STEM emerged in a society that is in need for more young people choosing for STEM careers. Therefore it is quite understandable that initially STEM-programs in schools tend to be oriented more towards the ‘happy few’. There is nothing wrong with STEM programs focusing on future scientists, engineers and technicians. But there might be something wrong if education is only doing that.

Schools in the PLC only realized during the process of the learning community that education cannot function if it is losing its societal meaning: to form literate and well-educated citizens. Therefore STE(A)M in schools cannot forget about STE(A)M literacy for all. In our PLC it became clear that many schools could not really explain for whom they were doing STE(A)M.

At the end of the PLC we came up with the following scheme that might clarify different stages in relation to whom you direct your STE(A)M to:

1. STE(A)M literacy for all
2. STE(A)M to explore
3. Focus on STE(A)M

The first stage ‘STE(A)M for all’ is focusing on citizenship and it stays important for all students at all ages. Of course, when students become older, from the middle school level towards high school, it is natural to diminish gradually the component ‘for all’ and make the ‘exploration’ stage or even the ‘focus’ stage more important.

The second stage ‘STE(A)M to explore’ gives students the time and space to go deeper into STE(A)M, to give them the opportunity to love the subject without the premise to make a STE(A)M discipline their job. Give them the opportunity to become maybe an ‘amateur’.

The third stage ‘Focus on STE(A)M’ is than for those who really choose for STE(A)M, who want maybe to make of a STE(A)M discipline their profession. It was recognized in this respect, that no one can ever be fully STE(A)M: you cannot become an expert in all components of STE(A)M. What you maybe can do, is study one or maybe two disciplines, and with these backgrounds you can go into the
interdisciplinary game that STE(A)M is, by working in a STE(A)M team in a research institute or in a company.

4. Conclusions
We proposed a pedagogical ‘model for polyphonic STE(A)M education’. The work in a PLC with teachers showed that it helped teachers and schools to rethink the why, the what, the how and the for whom of their STE(A)M education. Experiences in the PLC confirmed what was previously found by research, i.e. that good interdisciplinary teaching can foster motivation, creativity, problem solving skills and the like. STEAM learning across disciplines makes lessons more relevant to learners, they see how things are related and this seems to foster creativity and problem solving.

Learning across disciplines is not wiping out the disciplines themselves. On the contrary you need the reasoning and the inquiry methodologies of different disciplines in order to discover connections and see the greater picture. Diving deep into disciplines using their own inquiry methodologies was found to be not only pedagogically relevant for teachers but it was relevant to learners too: it told them what STE(A)M is all about. It was needed therefore to make connections between disciplines and different methodologies explicit to learners. In the examples was shown how physics can play its role between arts and engineering.

By reflecting on their practices of STE(A)M schools rediscovered, that, apart from aiming at children with talent for STE(A)M, it is still their duty to give children ‘STEM for all’ and ‘STEM to explore’ experiences.

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