Towards a Genomic Metaphor for Educational Technology Research

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Abstract Technology-Enhanced Learning (TEL), as many other research fields, has benefitted from the use of metaphors and analogies as "thinking tools" for emphasizing different aspects of this complex socio-technical area, and establish directions of future research. After reviewing some of the most prominent metaphors and analogies in TEL, the necessity of a new metaphor that not only considers the complexity of TEL adoption but also its inherent objective (student learning), is highlighted. Taking inspiration in the discoveries of evolutionary theory and genomics, we propose a new metaphor to guide educational technology research, with learning design and learning analytics at its core – that of the *learning scenario as an organism*, with student learning as the main factor of survival and evolution. We also discuss how this metaphor can guide both educational research and teacher development, and what research challenges need to be overturned to make this process of continuous improvement work.

Keywords: learning analytics, teaching analytics, learning design, metaphors, genetics

1 Introduction

Metaphors and analogies have been used for centuries in numerous realms of science, to derive new insights and to understand the relationships between parts and the whole of multiple scientific problems, from Archimedes' *Eureka* moment to the alphabet and structure of DNA [1]. Technology-Enhanced Learning (TEL) is not an exception to this: multiple metaphors have emerged in this field since its inception, highlighting selected challenges and research problems, from the analogy of a virtual campus that mimics many of the functions of physical university campuses [2], to the view of educational technologies as species competing for dominance in the school ecosystem [3].

Indeed, there is currently no shortage of challenges in TEL, from concrete challenges that emerge from the latest research and technology advances (e.g., [4, 5]), to wider societal challenges, such as the goal of achieving a more inclusive and reflective society[1] (an objective in which education undoubtedly plays a major role). However, while these emergent challenges are certainly important, there also are in TEL long-standing challenges that have defied researchers' attempts to a definitive solution. Maybe the most pervasive one is that of the *lack (or slowness) of adoption* of many TEL advances in practice. This gap between research and practice has been acknowledged not only in general about educational technologies [6], but also in many of the particular research areas that make up our field, from computer-supported collaborative learning [7–9] to learning design [10, 11] or learning analytics [12]. This challenge affects most sub-areas of TEL, and its eventual solution requires a rethinking of both (educational) technology design and the professional development of our teachers.

The problem of TEL's slow uptake has been approached from the metaphorical perspective as well, highlighting the complexity of factors (akin to an ecosystem [13]), and the need for practitioners to carefully orchestrate these factors [14]. The gap between research and practice of TEL, however, still remains. In this paper, I contend that a lack of focus on demonstrating the added value to student learning (the most obvious objective of any TEL innovation), may be at the heart of this unsolved problem. Indeed, recent reviews in different areas of TEL seem to support this intuition [15, 16]: few of the TEL innovations in those reviews actually tried to measure the effect of the innovation in students' learning (be it either a learning dashboard, or a tool for student reflection), and even fewer did so in evaluations occurring in authentic educational settings. But, why should stakeholders in educational practice adopt our innovations if we fail to demonstrate their added value?

This position paper argues that we need new metaphors to drive our TEL research more clearly towards demonstrably *enhanced* learning – metaphors which both acknowledge the complexity of adoption in everyday practice and the need to make learning our main objective (which itself calls for making learning "visible" [17] in some way with every innovation we enact). Drawing from evolutionary theory and genomics, I propose one such metaphor: that of "learning scenarios as organisms". This metaphor acknowledges the complexity of factors in TEL adoption, but also carries with it an approach where fine-grained analysis of learning design and multimodal learning and teaching analytics of a design's enactments can be used to improve both our understanding of learning as researchers, and everyday educational practice in the real world.

2 An Quick Overview of Metaphors on Adoption of Educational Technologies

Many metaphors and analogies have been used in education and educational technologies, from construction similes like scaffolding [18] (to denote how a tutor may support children in achieving learning tasks that may be just outside

[1] See the EU's Societal Challenges for the Horizon 2020 programme `https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges`.

their reach), or the notion of a virtual campus that mimics or complements the traditional (physical) university campuses [2]. Some of these metaphors are clearly focused on learning – comparing it with patchworking [19], acquisition or participation [20]. Others, however, looked more into parallelisms that common pedagogical structures have with other kinds of performance (such as the theatrical metaphor of acts, scenes and roles that underlied much of the early work on learning design [21]). While a complete review of metaphors used in TEL far exceeds the scope of this paper, below we review two of the main groups of metaphors that have been posited to address the issue of adopting technology in educational settings.

2.1 Learning Scenario as Ecosystem

Zhao and Frank [3] proposed to take an "ecological perspective" when studying technology use in schools, and why it may spread successfully (or not). In their study of technology uses of 19 schools, they looked at the introduction of a new computer use as similar to the invasion of an ecosystem by an exotic species. In this complex process, not only the characteristics of the species is important, but also the (school) environment, the teacher attitudes and compatibility with that particular computer use (i.e., teachers as a keystone species in the ecosystem), as well as the interactions between these factors. With this metaphor, the authors emphasized the complexity and multiplicity of factors that affect technology adoption, the evolution of this adoption over time (and how the computer use can fill in different ecosystem niches at different stages of adoption), or the importance of teachers (and especially, their perception of technology) in this process.

In a similar line of analogy, it is also worth mentioning Luckin's "learner-centered ecology of resources" [13], a conceptual framework to design learning experiences that address student needs, in which the process of matching the resources in the learner's context (including both people and objects) and the learner needs can provide insights to the design and evaluation of educational innovations. In this case, less emphasis is made on the ecological simile itself, which is used mostly to highlight the variety of resources involved, and the different roles and interactions between them.

Although these two ecological metaphors are very useful to analyze or describe a TEL context, helping underline the complexity and multiplicity of factors involved in technology use in education, one could argue that both of them are, by nature, *resource-centric* (even if the learner is visually in the center of Luckin's framework, learning is something that happens in the background betweeen the resource and the learner, without much attention being paid to how learning occurs or how it is evaluated). Hence, such ecological frameworks are good conceptual tools to analyze/describe technology adoption *post-hoc*, but may not be so useful to drive innovation towards more effective learning.

2.2 Orchestration

Another metaphor that has been widely used by TEL researchers in relation to the problem of learning technology adoption is that of orchestration. Dillenbourg et al. [14] considered the labor of teachers' coordination of learning activities as akin to orchestration in music (in the sense of mixing multiple instruments to achieve a desired learning effect). Although the simile of orchestration has been used with slightly different meanings by TEL research [22], and there is no general consensus about the level to which parallelism between both realms should be drawn (e.g., should it be rather called "conducting"? should learning design be considered part of orchestration?) [23], orchestration is generally thought of as referring to the challenges of adopting TEL in authentic educational settings [24]. The simile has been used, e.g., to prompt guidelines for learning technology that is more easily adoptable, by taking into account the multiple constraints of real classrooms and the need for teachers to follow and manage the multiple learning processes of a cohort of students [25].

As with the ecological metaphors, orchestration also emphasizes the complexity and multiplicity of elements that make up a modern TEL classroom, and especially the contextual constraints of everyday educational practice, such as curriculum, energy or discipline (which researchers working in controlled environments might disregard). It also highlights the importance of careful design and run-time facilitation by teachers, as crucial elements of a learning scenario. However, while the focus on orchestration can help design technologies that are more easily usable at the classroom level, by itself it does not constitute the ultimate goal of TEL (which is to improve student learning).

3 A New Guiding Metaphor: Learning Scenarios as Organisms

The aforementioned metaphors have highlighted important aspects of learning technology, and their potential and barriers for widespread impact. However, as we have seen, this impact has not been attained yet. An important missing element in those depictions of the complex process of adoption is its sense of direction: the fact that learning technologies and its use in authentic practice should be ultimately driven by their demonstrated ability to improve student learning. Rather than asking ourselves "How can my innovation be adopted in classrooms?", as researchers we should be asking: "*should* my innovation be adopted in classrooms?" and "*how* can it be used to achieve the desired learning effect?".

In the last decade, two areas within TEL have promised to put the accent back on student learning:

– Learning design [26] (or design for learning [27]) emphasizes the pedagogically-grounded preparation of environments and activities for effective learning. However, learning design has failed to gain widespread uptake among practitioners [11], and there exist few studies looking at the effect that implementing

learning design practices has on student learning. Even if approaches to learning design that measure learning as an integral part of its process do exist (e.g., teacher inquiry into student learning [28]), they require large efforts on the part of the teacher and hence remain largely theoretical.
- Learning analytics [12] holds the promise to analyze learning processes and outcomes, to better understand and improve them. Although studies of learning outcomes and their predicting factors abound in this field, innovations that provide the information back to stakeholders and demonstrate improvement in learning outcomes are much more rare [15].

The combination of these two fields has been proposed as a powerful enabler of improvement in education [29, 30], e.g., through continuous processes of design and inquiry into its effects on learning [28]. Together with large-scale studies of the learning outcomes achieved by different kinds of pedagogical strategies [17], these fields are set on the vision of finding the best pedagogical approach to facilitate learning. Several challenges, however, stand in researchers' way towards this vision. The variations in learning outcomes within categories of pedagogical approaches [17], and the fact that very often teacher practice involves a certain amount of improvisation around a high-level design [31, 32], seem to suggest that looking at general pedagogical strategies as the main unit of analysis (e.g., the provision of formative feedback to students improves learning), while certainly useful, may be incomplete (versus, e.g., the importance of *how* the feedback is provided). Furthermore, the fact that learning is highly contextual, and that our culture and our brains evolve over time, seem counter to the idea of pedagogical approaches having a definite, fixed effect on student learning.

To overcome these challenges in the joining of learning design and learning analytics to continuously improve both educational research and everyday practice, we can take inspiration on recent discoveries in evolutionary theory, which highlight the pre-eminent role of fine-grained replicator entities (genes) as the main drivers of evolution [33] – as opposed to group/species selection, or even individual organism selection. By considering the simile of *learning scenarios as organisms* that interact with their environment (including both institutional context/restrictions, and learners' individual brains) to produce learning outcomes (see Table 1). This simile leads us to the realization that much of educational research so far has been aimed at finding the *species* (i.e., broad categories of pedagogical scenarios) with the highest chances of survival. We know, however, that although species can be said to survive and go extinct, it is ultimately the *individual organisms* (i.e., the concrete enactment of a scenario in a particular context) that survive (i.e., produce learning). Furthermore, gene-oriented views of evolution posit that actually the survival of organisms itself is a byproduct of the co-evolution of the organisms' replicating building blocks, the *genes* (in our simile, the concrete elements of practice and technology that make up the enactment of a scenario). Indeed, Dawkins' own theory of the selfish gene also includes this kind of non-biological replicators spreading across different forms of human culture (the so-called *memes*, [33], chapter 11).

Table 1: Summary of the concepts in the "learning scenario as organism" metaphor, and their biology/genomics equivalents

Genomics context	Educational context
Species	Pedagogical / learning design approach
Organism	Particular learning scenario enactment
Genes	Routines / Design patterns / Activities / Tools / Roles
Survival (fitness)	Students' learning
Reproduction	Initial training / Professional development / Community of practice
Genotype	Learning design and its elements
Phenotype	Enactment, how the learning design unfolded

This metaphor, however, is limited by the fact that biological evolution is random, dictated by the changing context of the environment. If we want TEL to decidedly go towards better learning, and not be driven by the technological, pedagogical or policy fashions, the crucial element in our educational evolution (i.e., the survival by differential fitness of organisms to the environment) has to be based on empirical evidence of *learning*. Furthermore, the traditional way of evaluating this fitness/learning (through summative assessments at the end of the course) makes it very difficult to disentangle the effects of each individual learning scenario enactment. TEL innovations involving ongoing, everyday learning analytics are crucial to make such continuous improvement towards better learning, a reality.

The other main element in evolution is replication (i.e., reproduction). Currently, the way for these building blocks (the aforementioned "learning scenario memes") to propagate is through mechanisms like teacher education, professional development and informal spread in schools among colleagues (as noted in the ecosystem metaphor of technology adoption). These mechanisms are unnecessarily *slow* (i.e., currently allow few generations/mutations in the span of the professional life of a teacher), and the propagation can be hijacked with undesirable effects (as memes are known to propagate by taking advantage of our biases and heuristics [34]). Unless we manage to put visible learning at the center of our propagation of practices and technologies, we will not be able to make this evolution be an inequivocably good one. Here again, technology can help accelerate and improve the replication process, by supporting communities of practitioners and helping successful practices be replicated in other contexts (e.g., through targeted recommendations driven by learning outcome evidence gathered in authentic practice).

Hence, we propose a vision of the future of TEL research in which learning design and learning analytics collaborate to find the way to supercharge this evolution, by having *every learning scenario enacted in real practice* contribute to the survival and replication processes. This can be achieved by by gathering not only evidence of learning (i.e., fitness information) through everyday assessments and learning analytics (as anticipated partially by and [35], [28] and [36]). It also needs information on what are the building blocks of the learning designs used in practice, and the details of their enactment (through multimodal teaching and learning analytics, as foreshadowed by [32]) – something akin to the Human Genome project and genome sequencing technologies.

4 Towards Learning Design Genome Analytics: A Programme for Future Research

In the same way that genomics research differs from traditional biology and genetics, the aforementioned metaphor of the learning scenario as an organism prompts a novel, holistic approach to educational research and practice, based on the scaling up of learning design and analytics innovations. This vision of using technology to mine learning designs used in practice, analyze them and their enactment details, and help propagate those with greater added value in terms of learning outcomes, however, is still not feasible. Advances need to be made in several areas of educational and TEL research, in order to attain such ongoing, adaptable evolution towards more effective learning:

- *Theoretical work* is needed to find out what are the right building blocks that make up learning designs and pedagogical approaches (i.e., our "learning scenario genes"), in a way that can be both pedagogically-meaningful and perceivable by human or automated agents in authentic settings. These elements can be defined in a general, pedagogy-agnostic manner (such as the routines and patterns of design and enactment in [31]), or more specifically for each "species" (e.g., for inquiry-based learning). Wide-ranging reviews such as [17] can provide useful starting points for such theoretical work, and for the initial population of "fitness" (i.e., learning) values.
- In a similar vein, this vision requires defining the different *kinds of learning* that should make up the "fitness value" of a learning scenario (e.g., based on frameworks like Bloom's taxonomy [37]), but also on methods to *assess* these different kinds of learning in ways that are compatible with *everyday practice* constraints (e.g., continuing research lines tying assessment and learning design [38]).
- Given the low uptake of formal, computer-interpretable learning design in everyday practice (especially in certain contexts like primary and secondary school), alternative approaches like the mining of designs and enactments through *multimodal learning and teaching analytics* [32, 39] can provide crucial information about the "genome" of everyday learning situations, and their learning effects. These kind of techniques can be useful not only in less-controlled face-to-face settings, but also in online learning situations, to mine the learner's environment and the learner characteristics (which are part of the environment of our "learning design organisms").
- The aforementioned advances in defining the building blocks and survival value of learning designs, will need also from new *analysis methods* that are able to mine the structure of the learning designs, match them with similar

designs and with similar environments, and disentangle their phenotypic (i.e., learning) effects. These methods may or may not be a transposition of the machine learning methods used in genomics [40].
- *Ethical factors* like privacy, anonymity or trust are bound to play an important role in any technological innovation that tries to pervade everyday educational practice at a large scale. In this sense, recent advances in data analysis techniques that do not require centralized data availability and are able to maintain anonymity, or blockchain technologies applied to learning (and teaching) assessment and accreditation[2],[3], may be crucial to take teachers, learners and other stakeholders on board this kind of initiative [41].
- New *technological infrastructures* for the large-scale data gathering and analysis of such educational data (which can potentially have large volumes of data from multiple sources, and need to be processed and stored in a distributed manner to address the aforementioned concerns), will also be needed.
- The effects of this metaphor and the proposed approach on *teacher training and ongoing professional development* should also be studied, including the technological support to communities of teaching practice that help spread the most effective "learning design genes". This kind of support, which can be seen as the evolution of current proposals like [42], should also be complemented with further research on models of *teacher (and learner) decision-making* that not only consider these actors as rational agents, but also follows recent psychology advances on non-rational factors that affect such decisions in everyday life [34] (e.g., affective aspects, biases, etc.).

Education, however, is *not* biology, and this metaphor will break at some point. Caveats to this genomic vision of educational research can be done from the evolutionary theory side (e.g., that gene-oriented evolution theories do not take into account the crucial importance of how the same genes can be expressed in very different phenotypes, depending on their environment), or from education itself (e.g., the fact that defining and assessing learning reliably, on which the whole metaphor hinges, has proven to be a very difficult problem to solve). Nevertheless, we can also contend that the sort of ecologically-valid[4], large-scale studies proposed by this vision will enable us to come up with better theories of learning (since it will be based on teaching and learning happening in authentic settings). Regardless of whether genes are or not the "cause" for evolution, the metaphor helps focus our attention on two crucial mechanisms of TEL (the propagation of technologies and their uses, and their fitness to the rest of the environment in terms of achieving learning).

[2] https://campustechnology.com/articles/2016/05/16/how-blockchain-will-disrupt-the-higher-education-transcript.aspx
[3] http://teachonline.ca/tools-trends/exploring-future-education/uber-u-already-here
[4] In the scientific methodology sense (e.g., how well the studies approximate the real-world under study), no pun intended.

All these research-driven elements should be put together into a coherent approach that can be implemented in practice [35] and in an inclusive manner, lest this technological utopia bring more inequality to our educational systems [43]. Hence, the approaches need not only advance in cutting-edge technologies to mine learning design and analyze learning, but also find affordable face-to-face equivalents to the hi-tech online assessments that are becoming widespread in some sectors of industry. Indeed, I believe that this metaphor can not only improve our understanding of educational research, and provide real-world impact, but also spawn entirely new industries providing the necessary technologies and services needed for this vision to come true[5].

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