AUTHORS:
Valentino van de Heyde[1]
André Siebrits[2]

AFFILIATIONS:
[1]Department of Physics and Astronomy, University of the Western Cape, Cape Town, South Africa
[2]Department of Political Studies, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Valentino van de Heyde

EMAIL:
vvandeheyde@uwc.ac.za

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The ecosystem of e-learning model for higher education

We present the ecosystem of e-learning (EeL) model, which can be applied to any higher education context, and which takes full account of all inhabitants and their interrelationships, not only the components, of the e-learning food chain. Specifically, this model was applied to our context within the University of the Western Cape, highlighting the role of the academic developer within the model. A key argument advanced in this paper is that academic developers should work to reduce complexities associated with emerging e-tools. The EeL model is used to emphasise the role of academic developers as mediators between components and relationships.

Significance:

- By the application of the EeL model, it is demonstrated that the use of e-tools and their alignment with pedagogies within any context must be sensitive to the entire ecosystem, with the recognition that this is simultaneously a top-down and a bottom-up process.
- The student must be the core focus in the adoption of emerging technologies and the learning process, but simultaneously the student can only be in focus when they are placed within their broader ecosystem – including the societal level.
- Our findings add to the debate on physics education specifically, and more broadly by providing new ways of conceptualising an e-learning ecosystem.
- It is advocated that an academic developer-mediator should step in to mediate between academics, tutors and emerging e-tools, through a structured developmental process for learning and teaching.
- The EeL model can afford an insight into the processes involved when incorporating a learning management system (and emerging e-tools) into learning and teaching in higher education institutions.

Introduction

> *Science is more than a body of knowledge; it is a way of thinking.*[1]

Globally, science has been lauded as the ‘engine of prosperity’ – a reflection of its importance in promoting economic growth.[2] In Africa too, the importance of a scientifically and technologically literate and innovative population has been recognised as a precondition for achieving the aspiration of a ‘prosperous Africa based on inclusive growth and sustainable development’, as envisioned in the African Union’s Agenda 2063 Strategic Framework.[3] South Africa’s National Development Plan 2030 also recognises the crucial importance of science and technology for social development, economic growth and international competitiveness, and stresses that ‘[q]uality higher education needs excellence in science and technology, just as quality science and technology needs excellent higher education’[4]. It is therefore disheartening that the World Economic Forum’s 2016 Global Information Technology Report ranked the quality of South Africa’s science and math education as the lowest out of the 139 countries surveyed.[5] The South African education system in its entirety was ranked the third lowest. This represents a critical challenge to the country’s desire to overcome the legacy of apartheid and the continued inequality that pervades society.

The University of the Western Cape (UWC) was historically a disadvantaged institution under apartheid, yet it was able to achieve a ‘distinctive track record as an institution which enables people from sometimes severely disadvantaged backgrounds to succeed at university and aspire to excellence’[6]. While the science and math fields are critical growth areas for the university, there is a ‘shrinking pool of learners [who are] doing Science and Mathematics at school’, while the quality of that education is questionable, as the World Economic Forum report suggests. One of the strategies employed by UWC is to leverage learning technologies to help meet the challenge of providing quality education to ever-increasing numbers of students, while bridging gaps in their knowledge, particularly in relation to technology. As Merkoffer and Murphy[7] note:

> [d]*eveloping countries such as South Africa face a greater challenge owing to the larger deficit of available infrastructure to build e-skills at an educational and community level,*

while it is also

> *characterised by economic disparities resulting in a wealthy and educated minority having more access to information technologies and the disadvantaged majority increasingly being left on the other side of a growing ‘digital divide’.*

While this remains true today, UWC is attempting to bridge this divide through various initiatives.

Educational technologies for learning and teaching practices

The widespread adoption of learning technologies within higher education institutions (HEIs) globally has made it evident that e-learning serves a critical need, especially in developing-world contexts in which HEIs have limited resources. e-Learning in an academic context is defined here as the use of time- and space-independent application(s) designed to deliver multimedia content, such as assessments, discussions and communications to both academics and students. e-Learning can be supported by learning management systems (LMSs), other stand-alone software applications, or both in combination. Also, numerous HEIs are adopting new online learning environments to replace the traditional pen and paper methods of subject instruction.[8] For this study, we define a LMS as a web-based application that is used for educational purposes to disseminate multimedia resources, organise resources in a chronological manner, communicate with course participants (students, teaching assistants, tutors and others), and assess students' competencies, amongst other capabilities. This assessment, for example, includes higher-order question types such as the Calculated Questions, Numeric Response, Questions Pools, and Lessons[9]. Moreover, we argue that all LMSs share the same four core functionality categories: communication, assessment, management and content.

A large variety of LMSs exists today and can be divided into either commercial software (like Blackboard and Edmodo) or open-source software (including Moodle, Canvas, Claroline and Sakai). The most preferred of these are Moodle and Sakai. According to Cigdemoglu et al.[10], 'Moodle ... is preferred by a significant number of educational institutions' which is probably because of its ability to let the user '…create powerful, flexible and engaging online experiences', according to Rice[11]. On the other hand, Caminero et al.[12] showed that out of three open-source LMSs used in their study, 'Sakai is considered the best tool because it obtains high ratings in both evaluations'. This conclusion was based on the 'large community of users...[and it is] easy to install and use, and it is kept up-to-date'. To date, some studies have been done on the use and adoption of these various LMSs within HEIs, but the use and value of an LMS within the science field, specifically physics, remains under-researched. This is especially true for the Sakai LMS (https://sakaiproject.org), which is utilised by UWC, and branded as iKamva.

Emerging learning technologies within the learning and teaching environments of physics are generally underutilised in South Africa. The need for, and use of, these e-tools is of utmost importance as national HEIs are working towards a common goal within the context of a global education transformation. The Department of Physics and Astronomy at UWC is currently making use of iKamva's various functionalities for both theory and laboratory sessions. Despite the 21st century being well underway, it is still vital to introduce both academics and students to emerging technologies to enhance their current learning and teaching practices, especially within complex developing-world contexts.

By further leveraging iKamva, learning and teaching practices within our department can be better aligned with the *Institutional Operating Plan* [IOP] *(2016–2020) White Paper* of UWC. The IOP states explicitly that '[s]trengthening the informed use of technologies in learning and teaching is a central feature of the plan', and further states that the 'use of technologies must be underpinned by pedagogical rationales which draw on their potential to transform learning and teaching, especially by facilitating the active participation of students'[6]. Furthermore, the research will also focus on aligning e-tools use within physics to the university's Charter of Graduate Attributes, thus supporting the IOP's goal of promoting learning and teaching 'as a research-led process', while further positioning e-learning as a vital role player in promoting the Graduate Attributes.[6]

Purpose

Accordingly, this conceptual study presents our ecosystem of e-learning (EeL) model, which we use as a framework for implementing emerging educational technologies within our context in the Department of Physics and Astronomy, highlighting the role of an academic developer within the model. At the same time, it helps us contextualise the incorporation of educational technologies in a way that takes full account of all inhabitants of the e-learning 'food chain' (and their interrelationships, not only the components). In this way, we argue that globalised higher education initiatives and technologies must still be viewed and applied through the prism of more local awareness. The reason we have selected an image of an ecosystem is to emphasise the notion of a living, evolving and dynamic system. Our aim is for readers to contemplate how their initiatives with educational technology fit into their specific context and if, and how, this serves the broader needs of society. Another aim is to promote the further adoption of blended learning within science.

The methodology employed in this study is a variant of qualitative action research in that it is 'a disciplined process of inquiry conducted *by* and *for* those taking the action'. Like Sagor[13], we employ the 'primary reason for engaging in action research…to assist the "actor" [such as academic developers] in improving and/or refining his or her actions'.

The e-learning ecosystem

While our concept of an e-learning ecosystem draws on similar concepts from the e-learning literature, it puts these together in new ways and expands them in new directions. As stated, a biological metaphor was explicitly chosen to emphasise themes of adaptability and evolution – necessary key features in the field of emerging learning technologies, especially in developing-world contexts where innovative approaches are required to meet complex sets of demands and challenges. Indeed, as Cavus and Alhih[14] note, the 'educational process is evolving continually, such as a living organism'. The e-learning ecosystem we envision consists of a variety of components. These are the biome, the habitat, the ecotone and ecoline. The broader ecosystem will first be deliberated before we unpack these various components. While our concept of an e-learning ecosystem has commonalities with concepts employed by other scholars, there are also notable differences. Both will be highlighted throughout the discussion.

It is useful to begin with a definition of an ecosystem, for which two interrelated aspects are observable. First, at its most basic, an ecosystem is 'a community of organisms together with their physical environment'[15]. This definition emphasises the components of the ecosystem – the organisms that form the community, and their environment. Second, an ecosystem is also characterised as 'a system of ecological relationships' in which stability within the system is upheld because 'the relationships between the different organisms is such that each member mutually supports the continued existence of the other members and of the system itself'[16]. This definition thus privileges the relationships between the components. In our conception of an ecosystem, we focus on both these aspects – the components and the relationships.

This work is similar to that of Chang and Guetl[17], who expanded on earlier vague conceptions of learning ecosystems by focusing on the 'biotic and abiotic components [of an ecosystem] and all their interrelationships in specified physical boundaries'. This approach enabled them[17] to then arrive at a definition of learning ecosystems as 'consist[ing] of the stakeholders incorporating the whole chain of the learning process and the learning utilities, the learning environment, within specific boundaries'. These authors then applied the learning ecosystem model more narrowly to e-learning, specifically in relation to training initiatives within small and medium enterprises, by focusing on (1) the learning communities – in their view the learners, along with other stakeholders such as lecturers, tutors, content providers, pedagogical experts and information technology (IT) support and management; (2) the learning utilities and technology – such as an LMS; and (3) ecosystem conditions – such as 'cultural and sociological influences' and the demands of industry or government policy.[17] More recently, Eswari[18] defined an e-learning ecosystem as consisting of 'stakeholders, e-Learning portals, ICT infrastructure and processes', while Lohmosavi et al.[19], defined it as 'all the components needed to implement an e-learning solution', including 'providers, consultants and infrastructures'. However, these definitions privilege the components rather than the relationships within an ecosystem.

While there are thus similarities between these concepts of ecosystems and our use of the term, we specifically apply it to our tertiary education environment, in our South African context. This is why our model includes all elements from the LMS, through the HEI, to the broader society in which they are embedded. It then reflects the definitions of ecosystems given above, by including the components, the environment (virtual, physical, institutional and national), and their interrelationships. Our EeL model is presented in Figure 1. While we employ a broad metaphor of an e-learning food chain (to emphasise the interrelationships), and its attendant trophic levels, we strongly emphasise that none of these levels is more important than the others. Instead, the relationships between the components of the ecosystem take the form of constant dialogue. In this way, the broader societal imperatives (for example producing more qualified graduates in the science field) feed into the goals and plans of HEIs, and these set the context for academic developers and lecturers, ultimately filtering through to the students. These goals and needs must then be supported by any learning technologies employed within HEIs. At the same time, academic developers and lecturers must align the tools and their appropriate pedagogies with the needs of their students, in supporting the institutional goals and societal imperatives. This process is thus a continuous, fluid process that is simultaneously top-down and bottom-up, meaning that no part of the ecosystem can be privileged above another. However, we have arranged our model into a pyramid to reflect the attention and focus we place on the various components in this study. Hence, the primary component of our e-learning ecosystem that is under investigation here is the LMS.

Further focus is then placed, in diminishing order, on the academic developer and the lecturers, and how their use of the LMS lines up with the needs of students. Finally, as mentioned in the Introduction, no discussion of these can be fruitful without recognising the national and institutional context within which we operate. Importantly, however, the EeL model can be applied to, and customised for, any specific context or study (or trophic level).

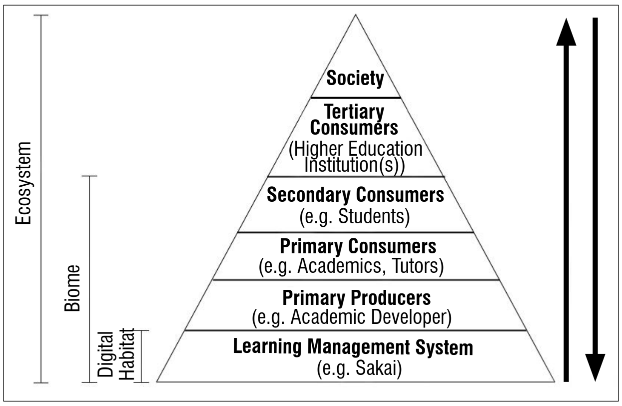

Figure 1: Ecosystem of e-learning model.

The physics biome and digital habitat

As mentioned in the Introduction, the specific learning community we focus on in our study is the Department of Physics and Astronomy at UWC. In line with the EeL model, this includes the academic developer(s), lecturers, tutors, teaching assistants and students, along with the LMS used within the institution – iKamva/Sakai – as well as the relationships between all role players. In an extension of the biological metaphor, we refer to this as our specific e-learning biome. A biome can be defined as 'a major ecological community type'[20]. In our view, while it is necessary to guard against viewing biomes as silos (by embedding them within the broader, shared ecosystem), it is still equally necessary to break this broader academic ecosystem into specific disciplinary biomes because the e-learning contexts and requirements of disciplines vary. For example, the science field is notorious for what Habibi and Habibi[21] call its 'abstract nature', which can contribute to high attrition rates, especially when combined with inadequate knowledge on the part of the educator, or unengaging or 'obsolete material'. This potentially leads to some 'students [being] forced to lose interest, motivation and passion; [and ultimately] in some cases frustration sets in and students abandon the discipline or subject matter'. This is a legitimate concern when paired with the challenges of South Africa's school system, which often leaves new students underprepared for grappling with complex and abstract concepts at the tertiary education level. Therefore, one of the challenges facing physics educators is to impart more than content knowledge, and to 'bring about scientific thinking in students' – as Carl Sagan's quote highlighted at the beginning of this paper – and this constitutes a transformed 'mindset… [that] requires students to test out, through experimentation'[21].

Achieving this transformed mindset is why we combine our specific LMS with our learning community (and its members) to form the biome, which is reflected in the specialised interrelationships within physics specifically, and how the LMS and its tools must be aligned with the needs of the department. The learning demands and challenges of each learning community will thus necessarily differ, and this must be taken into account when selecting specific tools and educational technologies, meaning that an LMS cannot be viewed in separation from the community it must serve. Martín-Blas and Serrano-Fernández[22] reinforce this notion by reflecting on the value of LMSs for physics education specifically, by highlighting the ability of LMSs to allow the use of

> *objects of many kinds such as: videos, mp3s, text documents, scanned images, links to other websites or animations which can be used to show dynamically many physical situations and concepts that are often difficult to apprehend by the students.*

This multi-modal approach is what Salihi[23] refers to as contextualisation, where 'learning takes place in real-life situations or in situations simulating real-life instances', assuming that 'the learning environment setting allows for authentic and real-life learning experiences'.

Having discussed the broader e-learning ecosystem, and our departmental biome, we now turn to the specific (digital) habitat of this biome. Our concept of habitat is in line with the work of Wenger et al.[24] While a learning community's habitat can be both physical and digital/virtual, these authors note that 'community habitats [increasingly] include technology-based connections and places in addition to physical ones', and these digital habitats can be thought of as 'the portion of a community's habitat that is enabled by a configuration of technologies'[24]. Importantly, a digital habitat thus not only consists of technological aspects, but more broadly 'reflects the practices that members have developed to take advantage of the technology available and thus experience this technology as a "place" for a community', meaning that a 'digital habitat is first and foremost an experience of place enabled by technology'[24]. Four perspectives have been proposed regarding these digital habitats, focusing on the (1) tools, (2) platforms, (3) features making the tools usable and (4) full configuration of technologies.[24] Our perspective on the digital habitat used in our departmental biome is in line with the latter, the configuration perspective, which considers the 'full technology substrate' of the habitat.[24] The fourth perspective applies to our departmental biome because, while the department and the broader institution mainly rely on the iKamva LMS, personal learning environments and other standalone software applications are also frequently used. Wenger et al.[24] elaborate on the configuration perspective as including:

> *the overall set of technologies that serve as a substrate for a community's habitat at a given point in time – whether tools belong to a single platform, to multiple platforms, or are free-standing. For communities with complex sets of activities, the full configuration often involves multiple platforms, or selected tools from different platforms combined with a main platform. Even communities that appear to only use one platform usually depend on other tools (including backchannel emails, phone calls, public web spaces, and other means of collaboration) that are not part of the 'main platform'.*

This is indeed the case for UWC. It should also be pointed out that while personal learning environments may at first glance appear, because of their individually focused nature, to be removed from the concept of 'place' for a community, they still require the same guidance and pedagogical alignment as tools within the LMS in order to meet the specified learning outcomes and objectives. It also cannot be assumed that users will automatically know how to navigate Wikis, Google Docs, blogs or other personal learning environments. Hence the need for the learning community's relationships to come to the fore, for example, through training initiatives. In line with the EeL model, we explore our digital habitat in relation to its use by members of this biome (and thus not in isolation as a mere list of affordances or features). The following section will delve deeper into this digital habitat, specifically in relation to science education.

This focus on relationships within the biome brings to the fore the role of an academic developer as a mediator between the digital habitat and the rest of the biome. For this reason, Figure 1 depicts the academic developer as primary producer within the e-learning 'food chain' (or e-chain). Mediation, in this sense, refers to acting as a knowledgeable but impartial go-between linking the digital habitat and the rest of the biome, by helping to align the tools to both primary consumers (i.e. academics, lecturers, tutors, teaching assistants) and secondary consumers (i.e. students). This mediation requires taking into account all academic needs for learning and teaching, as well as being aware of emerging learning technologies and their affordances for physics. In turn, ultimately, this mediation can promote awareness within the broader ecosystem, specifically the rest of the institution – the tertiary consumers (i.e. other faculties and departments) – and eventually the rest of society – the apex. Thus, ideally, the academic developer-mediator ultimately serves to reduce complexity within the ecosystem and to reduce the opacity of lesser-known emerging technologies that can be of service to the primary consumers, secondary consumers, tertiary consumers and broader society.

An important caveat is that not all primary consumers within our biome are making use of the digital habitat. Most primary consumers are not using any part of the digital habitat. One of the ultimate aims of this study is thus to promote the further adoption of blended learning within the department. A critical element to this aim is that this promotion takes place from within the department itself, because both the primary producers and primary consumers within our model understand the particular needs and requirements of physics education intimately, and thus what features of the digital habitat can speak most directly to these. The role of champions among the primary producers and primary consumers must not be overlooked. Those individuals who are currently making use of the 'full technology substrate' of the digital habitat are best placed, through their experience, to model the benefits and advantages of emerging learning technologies to their colleagues. As the United Kingdom's National Health Service[25] notes:

> *e-Learning Champions work at the front line. They understand the practical issues that colleagues face but have the wherewithal to bridge the gap between desire and execution of e-Learning. They can act as intermediaries, lobbying for resources and training time with managers and encouraging colleagues to make best use of both. To do this, their role must be respected, recognised and rewarded.*

This front line can be described by another biological metaphor – the ecotone and the ecoline. An ecotone is defined as 'an area of relatively rapid change, producing a narrow ecological zone between two different and relatively homogeneous community types', and these transition areas are 'highly dynamic and usually unstable, resulting in an environmentally stochastic stress zone', resulting in 'fluctuations [that] are strong and … a time-series of strongly different, but individually relatively homogeneous, environments'[26]. Put another way, ecotones are sharp boundaries between different communities or organisms that produce tensions and uneven pockets of communities along the boundary zone. Ecolines, in contrast, are boundaries of 'more gradual, progressive change … between two systems', being a

> *response to the gradual difference in at least one major environmental factor, whilst a further factor (acting at a different scale) influences the total differences within the gradient, yet maintains all the transitional states.[26]*

These are useful analogies in the field of e-learning, including for our context, because there are boundaries present within the same biome (the department, but also for the institution as a whole) between those who are making use of emerging learning technologies and those who are not. Without champions, this boundary is more akin to an ecotone, with abrupt changes and tensions and with relatively homogeneous 'pockets' of adopters and non-adopters. While progress may be made in terms of more academics exploring and provisionally adopting emerging learning technologies in their teaching, because this zone is unstable (if there is no proper support or guidance), this change may not last. In contrast, where there is strong support from within the institution and biome, and with champions paving the way and sharing their successes with their colleagues, the boundary between adopters and non-adopters may be more like an ecoline. An ecoline thus entails more and more individuals trying out emerging learning technologies, initially on a very small scale (for instance one or two tools), but gradually gaining more experience and confidence to adopt more. Our biome is characterised by such an ecoline, and by sharing some of the work being done by champions within the department, we hope to align the biome with the digital habitat further, which is depicted in Figure 2.

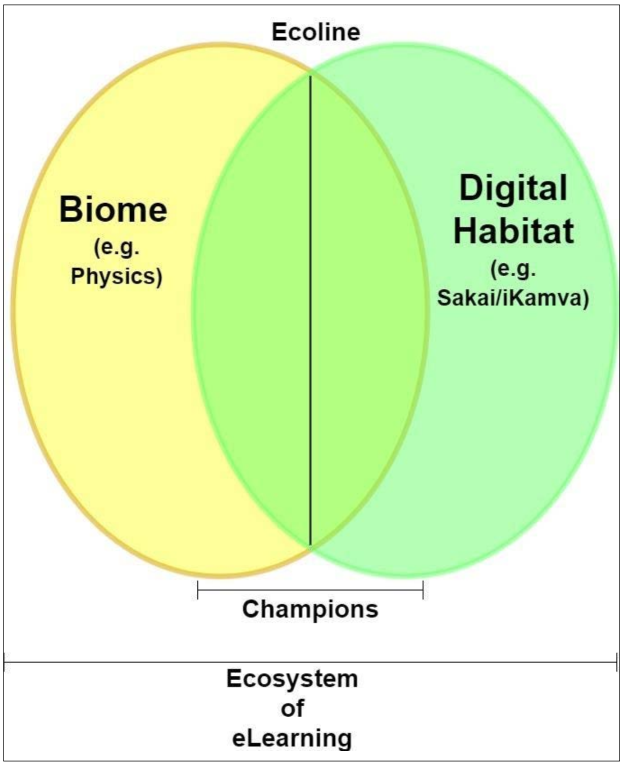

Figure 2: Representation of an ecoline within a physics education context.

The physics digital habitat

In this section, the physics digital habitat will be explored in greater depth. As mentioned, in line with the configuration perspective, this digital habitat includes more than the LMS platform. However, we will focus specifically on e-tools within the Sakai LMS that are underutilised. In the e-learning literature there is a dearth of research on the Sakai LMS platform, especially in terms of its use in the science field, and even more so in the physics education context. However, some studies have been produced concerning the utilisation of Sakai in other academic fields. One example is the work by Wannous and Nakano[27], which explored the integration of a 'stand-alone web-based laboratory (NVLab)', which they developed, into Sakai in support of computer networks online courses.

However, in the science field, and specifically in physics, studies have been done on the use of other LMSs for learning and teaching. Martín-Blas and Serrano-Fernández[22] showcased the main features of their (online) physics course, implemented in Moodle. One of the observations they make is that LMSs are valuable tools for assisting with the teaching of physics courses specifically, and science courses more generally, because, as mentioned above, successfully promoting scientific thinking depends on students 'develop[ing] the ability to solve problems that represent different (more or less complex) physical situations', while those same students may struggle 'to apply the laws and equations they have seen in the classroom'[22]. More recently, Murakami et al.[28] proposed an LMS for physics education by 'using the internet in combination with a wide-ranging selection of learning objects with remote access experiment integrated into Moodle's … learning management system'. According to Cavus and Alhih[14], LMSs 'are considered to be largely applicable for natural sciences as they enable representation of phenomena, foster experimental study and enable the creation of models and problem solving applications', but still there is a lack of LMS within science modules, especially physics. This use of an LMS for physics education employs a further set of skills including higher-order thinking and learning, constructivist pedagogy and digital competency in the use of emerging technologies.

Conclusion

One of the goals of the primary producer (academic developer) is to incorporate e-tools within all of the physics courses within the department. This incorporation necessarily progresses at a gradual rate, as it involves a 'structured developmental process' (as Salmon[29] advocates), including phases of introducing the primary consumers to the e-tools, aligning the e-tools to their learning and teaching methodology (as well as learning theories), designing and developing with related ePedagogy and finally implementation and evaluation. Part of this process involves grappling with what Matthews[30] identifies as a 'source of inertia [among academics, namely] the need to hang on to their "personal identity affirmation"', to avoid appearing less knowledgeable in front of students. This grappling is directly related to mediating between the digital habitat and the rest of the biome, in the sense of translating pedagogy into ePedagogy, which can be defined as a 'specifically designed set of principles and practices that focus on how to deliver…content to those using technology in their learning'[31]. We summarise and illustrate these concepts of overcoming inertia within academia and mediating between the digital habitat and the biome. In doing this, we draw on the TPACK model[32] and Gartner Hype Cycle[33]. By creatively combining the three facets of knowledge, namely subject matter, e-pedagogy and technological, our TEeL model adaptation can assist in avoiding the peak of inflated expectations and trough of disillusionment.

Thus, the goal of the primary producer is to empower the primary consumers, so that they, in turn, can empower other academics not currently making use of e-tools. This empowerment is part of the effort to ensure the gradual transition linked to the ecoline concept. The EeL model outlined earlier can afford an insight into the processes involved when incorporating a LMS (and emerging e-tools) into learning and teaching in HEIs. Ultimately, this process represents advocacy of reducing the complexity for academics within HEIs, in line with our philosophy of the primary producer as academic developer-mediator. Indeed, it is often lamented how complex, emerging technologies pose a challenge to many academics, without steps being taken to showcase these technologies and their tools in a manner that is tailored for a particular digital habitat (like Sakai), biome or ecosystem. This study is thus an exercise in creating and spreading awareness ('phases of introduction' as mentioned above).

However, while a LMS possesses many positive benefits to all 'organisms' within a biome, there are also challenges. One is the lack of pedagogical progress in physics education, which is linked to the fact that not all primary consumers within our biome make use of an LMS, and thus they only contribute to traditional pedagogical achievement, but not ePedagogy. Here the academic developer-mediator steps in to mediate between primary consumers and the emerging e-tools, through a structured developmental process – for instance helping academics to align themselves with the IOP White Paper[6], which recognises the benefits of being a 'smart' university.

Today's tech-savvy students and staff prefer an interactive and engaging experience and expect flexible and secure IT tools, systems and spaces to be available to them inside and outside the classroom. Universities face a large and growing challenge to use technology creatively to meet learning, research, administrative and support goals across a broad front. UWC has embraced the challenge.

We have used the concept of the e-learning ecosystem, and the EeL model to situate our work within its broader context, and to emphasise both the components and the relationships within this ecosystem. We thus aim to contribute to both the debate on physics education specifically and more broadly to provide new ways of conceptualising an e-learning ecosystem.

By advocating the EeL model, we also argue that at all times the student must be the core focus in the adoption of emerging technologies and the learning process, but, simultaneously, the student can be the focus only when they are placed within their broader ecosystem – including the societal level. Thus, the EeL model is a promising lens to help focus future research, especially concerning the concept of the academic developer-mediator.

One of the main arguments elucidated by the application of the EeL model is that the use of e-tools and their alignment with pedagogies within any context must be sensitive to the entire ecosystem, with the recognition that this process is simultaneously top-down and bottom-up. We argue that by planting seeds within a biome through the work of the academic developer-mediator, the whole e-learning ecosystem can become empowered, leading to overall advancement in learning and teaching for all involved. As the UWC IOP White Paper notes: 'UWC is committed to a major programme of technology-enabled management and learning

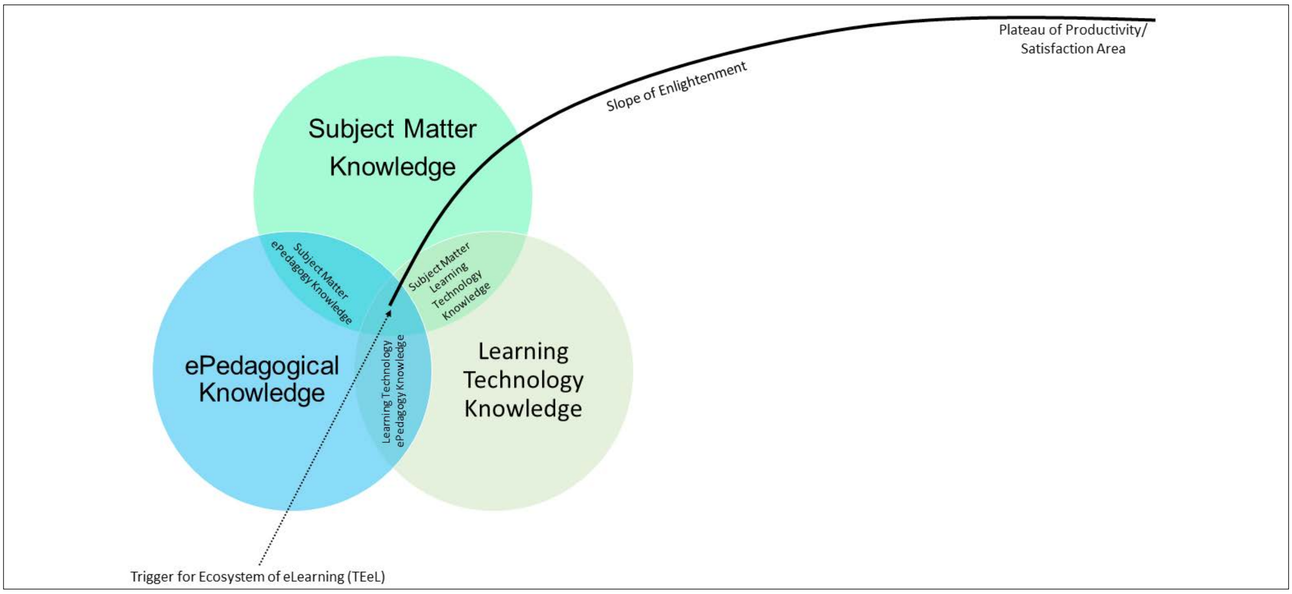

Figure 3: Trigger for ecosystem of e-learning model.

and we will systematically improve infrastructure and systems and our capacity to use them to maximal advantage'[6]. By employing the EeL model, this paper represents a contribution towards unlocking the full potential of this technology-enabled learning and teaching with our context. In this way, echoing Sagan, we emphasise the importance of the *education* of science as a way of thinking, not just a body of knowledge.

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Authors' contributions

V.v.d.H.: Conceptualisation; methodology; data collection; data analysis; writing; student supervision; project leadership; project management. A.S.: Conceptualisation; methodology; data analysis; writing; project management.

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