

Harnessing the Beast - COVID-19: Integrative Knowledge-Building with LCT Autonomy

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Abstract: Cytology is one of the core sections of introductory first-year Biology courses. Laboratory practicals form an integral component of these Cytology curricula - experiential learning through microscopy which students find fascinating and engaging. In contrast, we found that students are much less enthusiastic about the theory part presented during lectures - they perceive the content as being complex, high in volume and due to scale, often purely theoretical. Applicable real-world context is often far removed from the lived experiences of most students. However, the dramatic arrival of Coronavirus disease (COVID-19) early in 2020 presented vast and new possibilities for these lectures and was therefore selected as narrative to teach certain Cytology concepts to improve engagement and equip students for the future challenge. The ARCS (Attention, Relevance, Confidence and Satisfaction) Model of Motivational Design Theories underpins the rationale for using this narrative, whereas the Autonomy dimension of Legitimation Code Theory served as a theoretical framework to enable integrative knowledge-building. This strategy integrated two different bodies of knowledge, science and health science. It further harnessed the uncertainty caused by the novel virus to evoke a deeper level of curiosity and motivation among the students, who were visibly engaged in this Cytology offering.

Keywords: COVID-19, Current real-world events, integrative knowledge-building, legitimation code theory, LCT's autonomy dimension.

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Introduction

Coronavirus disease (COVID-19) appeared on the world's radar early in 2020 (WHO, 2020b). It commanded the attention of all - governments, world leaders, scientists, academics and regular people. After only a few short weeks, the pandemic brought the entire world to a confusing standstill. Overnight, unimagined procedures became the 'new normal': social distancing, screening, testing, personal protective equipment (PPE), the compulsory wearing of masks, etc. (WHO, 2020e). Everyone on the planet became consumed by a biological phenomenon, the novel Coronavirus causing COVID-19. The pandemic posed a potentially lethal risk, and people became fixated on information about the spread and nature of the disease. Moreover, trying to understand became an obsession to many, with reporters labelling it an 'infodemic' (WHO, 2020a). As a Microbiologist my first thoughts were: I have trained for this my whole life! But, witnessing the confusion and panic among my students and other citizens made me realize that knowledge and understanding of biological phenomena such as viruses, are anything but common knowledge to the majority.

In this article, I want to take a step back in time to early 2020, and focus on the events and face-to-face lectures that took place shortly after we became aware of the new disease, COVID-19, caused by a novel Coronavirus. Legislative lockdown had not yet been announced. News agencies reported the outbreak in Wuhan, China (WHO, 2020b). But it was only possible to understand the scope of this new disease when soon after Italy was struck hard, followed closely by Spain, and the suffering and dying of thousands of people, sent shock waves through the world (WHO, 2020c). We watched in terror as the virus started spreading around the globe... My teaching block of first-year cell biology (Cytology) was approaching and I realized that the unfolding world-event presented a whole new, very current, real-world scenario for these classes. Little did I know how the global situation would intensify further! This was around the time that the disease was escalated from 'epidemic' to 'pandemic' status by the World Health Organization (Cucinotta & Vanelli, 2020; WHO, 2020d). This was also before the so-called lockdown, and before our university had to suddenly abandon face-to-face teaching and join most others on the online platform....

Biology is a dynamic science - new discoveries, especially in the field of molecular Biology, are made and published at a remarkable rate. But occasionally, the frequency of new breakthroughs spike because of real-life events, such as disease outbreaks or even pandemics, which are far less common. Biology encompasses a wide spectrum of fields: Botany, Zoology, Microbiology, Biochemistry, Genetics, Physiology, Anatomy, many agricultural disciplines, the entire field of

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health science, etc. In our first-year Cell Biology course, we teach students the core biological concepts and the more specialized biological disciplines then build on these foundations in subsequent years. Cytology – one section of the Cell Biology module - is the study of the structure and function, but also the multiplication and pathology of individual cells. A core component of the curriculum involves laboratory practicals where students get the opportunity to perform microscopic examinations on different tissues and cells, and most students find this experiential learning extremely exciting and fascinating. In contrast, students are far less enthusiastic when it comes to the theory part presented during lectures, due to the content being complex, high in volume and due to scale, often purely theoretical. Most of the cell structures taught are far out of the reach of an average light microscope and can only be studied using electron microscopy. Moreover, they have been introduced to some of these concepts in school - although in much less detail, and therefore students have a rather superficial understanding of these concepts. When teaching Cytology, lectures often keep to the content as presented by the textbooks – high volumes of complex concepts, with little to no real-world context. Examples of context/application can often be found in the field of medicine, and although these may offer some real-world perspectives, these examples are often far removed from the lived experiences of most science students. Although we have explored ways to make the Biology content more accessible and relatable to the majority of students (Mouton, 2020; Mouton & Archer, 2019), certain topics still present challenges as explained here. For lecturers, it is often difficult to keep these classes engaging and relevant as part of a student-centered, active learning approach. However, COVID-19 presented a new opportunity and new perspectives on many of the Cytology concepts.

Keller's (1987, 2010) ARCS Model of Motivational Design underpins the rationale for using COVID-19 in the Cytology classes, as presented in this article. Four aspects promote and sustain motivation in the learning process: Attention, Relevance, Confidence and Satisfaction (Keller, 1987, 2010). Firstly, a lesson/class needs to capture the students' attention. One of the methods that Keller proposed to evoke a deeper level of curiosity is through perceptual arousal - the use of surprise or uncertainty by using a novel, surprising, strange, and/or uncertain event. COVID-19 certainly ticked this box. Secondly, if a lecturer succeeds in evoking curiosity, Keller (1987, 2010) explained that motivation can still be lost if students do not perceive the content as valuable. Instructors, therefore, need to establish relevance to increase motivation by among others, showing the content's 'present worth' and 'future usefulness.' Relevance, therefore, results from connecting the content of instruction to the relevant goals of the learners, their past interests, or current events. COVID-19 also ticked this box. At the time, rumours were doing the rounds that the university may close and move to the online space to help curb the spread of the virus. This was inconceivable at the time and led to much uncertainty and anxiety among the students. I reasoned that helping them to understand the biology of the 'enemy' may not only help to relieve some of the immediate stress, but also provide knowledge for the future - thus, speaking to Keller's (1987, 2010) aspects of confidence and satisfaction. Apart from the objectives and fundamentals that were part of the module, the inclusion of COVID-19 would help students grow - to navigate real-life circumstances and provide them with some form of control over unknown variables by understanding the behaviour of the virus and how they could mitigate their own actions to limit their risk of contracting and spreading the disease. Keller's (1987, 2010) aspect of satisfaction was thus incorporated, by building the student's knowledge that could be valuable in the new real-life situation.

In this article, I aim to describe a first-year Cytology lecture presented in March 2020, and the way in which the COVID-19 "beast" (situation) was harnessed by using a gripping and graphically animated film of a viral invasion, to teach the following eukaryotic cell structures: the cell membrane, the extracellular matrix (ECM), the cytoskeleton, lysosomes, motor proteins, the nucleus and the nuclear envelope. I will also show how Legitimation Code Theory was employed to facilitate integrative knowledge-building from two bodies of knowledge.

Methodology

Conceptual framework for learning design: Legitimation Code Theory's Autonomy dimension

Legitimation Code Theory (LCT) is a multi-dimensional toolkit for evaluating and shaping practice (Maton, 2014a, 2014b). The LCT dimensions have specific concepts or organizing principles underlying practices, dispositions and contexts. The Autonomy dimension of LCT explores the relations among practices as *autonomy codes* (Maton & Howard, 2018, 2020) and is based on the assumption that any set of practices consists of constituents or components that are related to one another in certain ways. Constituents or components may refer to content, ideas, actors, elements, etc. How these components are related, may be based on practices, procedures, mechanisms, rules, etc. Thus, Autonomy explores the degree of insulation, how insulated the parts are, and how insulated the ways that they relate together are.

The two concepts or organizing principles of Autonomy are (Figure 1):

- *positional autonomy* (PA) - the relative position of a component within a context in relation to the relative position of components within other contexts; and
- *relational autonomy* (RA) - the relations among components of a context and the relations among components of other contexts.

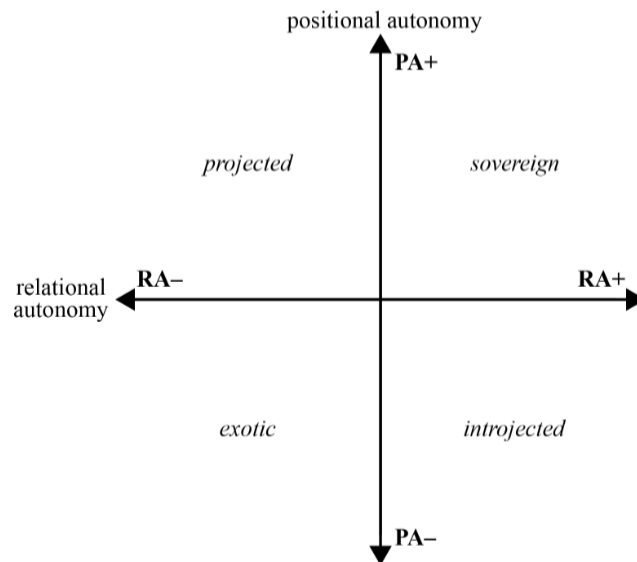


Figure 1. Legitimation Code Theory's Autonomy Plane (Maton & Howard, 2018)

Positional autonomy and relational autonomy can both be weaker and stronger along a continuum of strengths (Maton & Howard, 2018, 2020). In this case, stronger (PA+ and RA+) refers to more insulation and weaker refers to lesser insulation (PA- and RA-).

In this article, I focus on a first-year Biology lecture - the part of the curriculum on the structures and processes in eukaryotic cells as the core or target content for the purpose of teaching/learning Cytology. Positional autonomy (PA) therefore refers to where the content knowledge comes from. Thus, the target knowledge would represent stronger positional autonomy (PA+), whereas knowledge from somewhere else would be weaker in positional autonomy (PA-). How the components relate has to do with the teaching practice and how certain content is utilized during lectures or the purposes to which the knowledge is being put, in LCT terms known as relational autonomy (RA). Thus, if the knowledge is being used for teaching and learning the structures and processes in eukaryotic cells, it would be stronger in relational autonomy (RA+) and if being used for other purposes, it would be weaker in relational autonomy (RA-).

The four autonomy codes (Figure 1) occur where one considers stronger (↑) and weaker (↓) positional autonomy and relational autonomy: the *sovereign codes*, *exotic codes*, *introjected codes* and *projected codes*. For the *sovereign codes*, the learning content of the target is valued, and it is used for the purpose of learning the specific section of Cytology, the module content (internal parts used for internal purposes). For the *exotic codes*, the learning content comes from other sources and contexts, and it is used for other external purposes, other than teaching and learning Cytology (external parts used for external purposes). The *introjected codes* are characterized by content from other contexts or sources that are employed for teaching and learning Cytology (external parts turned to internal purposes). For the *projected codes*, the target content was used for purposes other than teaching and learning Cytology (internal parts turned to external purposes).

Table 1. The Generic Autonomy Translation Device of Maton and Howard (2018)

PA/RA	First Level	Second Level
+	Target	core
↑		ancillary
↓	Non-target	associated
-		unassociated

The Autonomy concepts have the capacity to be enacted in real-world practices (Figure 2), such as the content used for classes. Thus, the autonomy codes explore how knowledge practices are constructed, in this case by the lecturer during a lecture to facilitate integrated knowledge-building for the students. It is therefore very important to determine the target content (Table 1), and what lies beyond the target, and then to plan how to integrate these cohesively. It has been shown that simply bringing together different knowledge content or practices, does not mean that integration takes place. Instead, there should be a rationale behind the materials or practices that are selected, repurposed and connected (Maton & Howard, 2018, 2020). Purposeful shifts on the autonomy plane lead to so-called Autonomy tours and pathways (Figures 2A and 2B), thus engaging and cohesively integrating different knowledge practices or content. In contrast, poor instructional design produces so-called 'stay' or 'one-way' Autonomy pathways (Figures 2C and 2D), which leave

different knowledge practices or content segmented and disconnected (Maton & Howard, 2018, 2020). Thus, to incorporate different knowledge practices or content such as COVID-19 into classroom pedagogy, requires careful planning and purposeful design. For the lecture presented in this article, I used the Autonomy dimension of LCT for purposeful instructional design by planning Autonomy pathways, a key component to integrative knowledge-building.

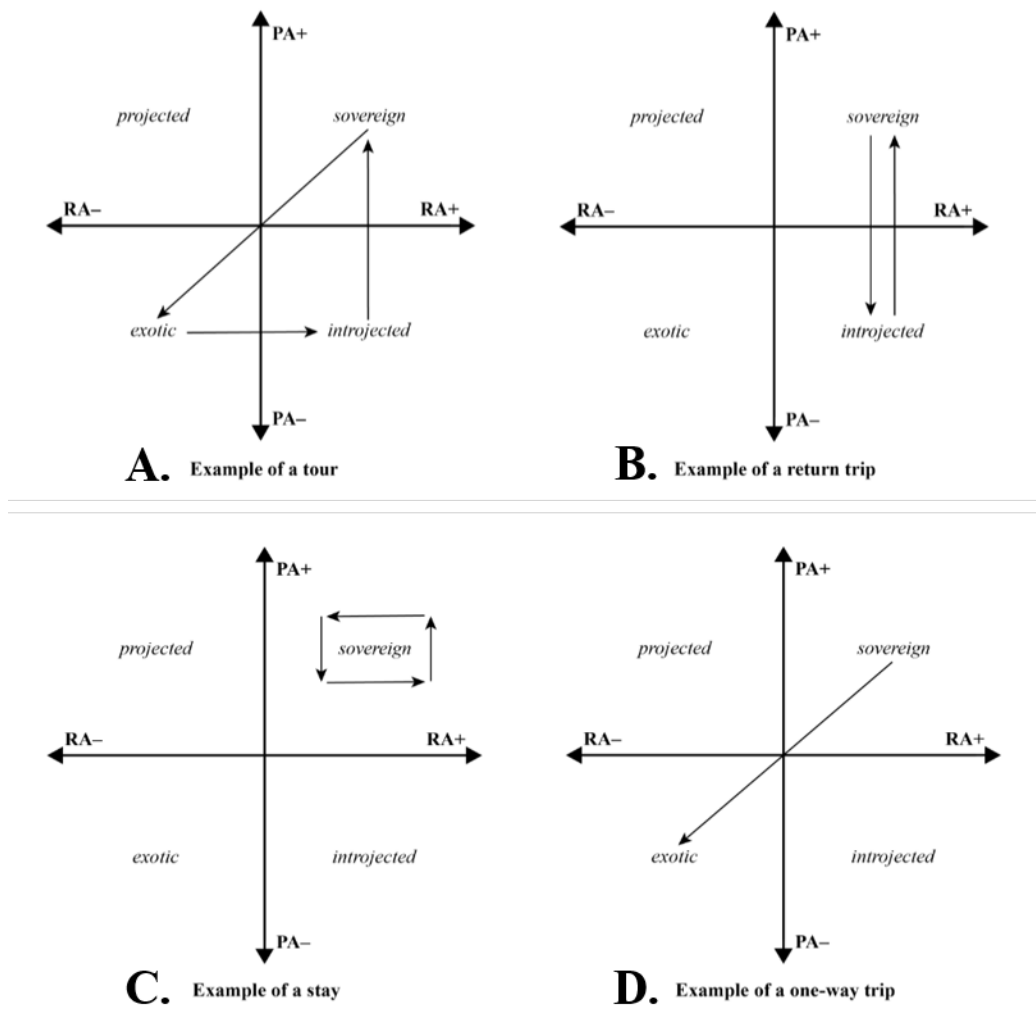


Figure 2 A-D. Examples of Autonomy pathways as published by Maton and Howard (2018)

The Biology Lesson: Content

Biology 124 is an introductory first-year Cell Biology course, consisting of four submodules: Biochemistry, Cytology, Genetics and Evolution. It involves the study of life at cellular level, as well as the study of evolution as an ongoing process on Earth. This module is taken in the first semester of the first year and stretches over 13 weeks – each week offers three lectures and a three hour practical class. These classes are taught in two languages (English and Afrikaans) and are attended by 950+ students (300+ students at a time).

Biology 124's Cytology section stretches over two and a half weeks and follows after four weeks of Biochemistry learning content. In the Cytology block, the topic of the eukaryotic cell is spread over two lectures, which includes the nucleus and nuclear envelope, the endoplasmic reticulum, the Golgi body, lysosomes, trafficking vesicles (all included in the endomembrane system), ribosomes, mitochondria, the cytoskeleton and motor proteins. The extracellular matrix and cell junctions of animal cells, as well as specialized plant cell structures are also included in these lectures. Since these classes are attended by 300+ students at a time, active learning experiences are extremely challenging to incorporate. In the past, we have included the making of concept maps during these lectures where students had to construct a concept map for each organelle to show how the concepts relate to one another. Each organelle's concept map was then integrated into an all-inclusive concept map for the complete cell. Many students participated and reported that it made them see more detail and also provided a more comprehensive view of the cell as a whole. In 2019, we also had a debate at the end of the topic, where groups of students had to represent each organelle and debate its 'worth' in the cell to avoid being 'removed due to budget cuts in the cell city'. These active learning activities improved engagement in the large classes and limited timeframe of the module. The plan was to incorporate these activities again in 2020. However, once the news

of COVID-19 broke, the students became increasingly concerned and even fearful in general, and had many questions about the virus and its method of infecting human cells. It was at this point that I decided to rather 'harness the beast' (situation) and incorporate a 'viral infection' into the lecture - some viruses are known to affect and hijack a number of cell structures. The new lecture plan was therefore to teach these cell structures by using the narrative of a viral infection.

The Film

Since modern-day students are 'wired to sophisticated, complex visual imagery' (Rothman, 2014), and this method had been shown to promote motivation and learning (Jandhyala, 2017), I decided to use portions (clips) of a graphic animation film as a visual narrative. Visual storytelling through film adds considerable value and goes beyond entertainment to enable student engagement by the addition of interest and humour (Taylor et al., 2018). A strong positive correlation has been found between the use of visual narratives and improved student engagement (Yousuf & Conlan, 2018). Harris (2011) stated that she enjoys the excitement and energy brought into the classroom with visual aids such as a film - for an ideal inspiring, creative learning environment.

The chosen film, 'Our secret universe: The hidden life of the cell' was produced by the BBC (<https://www.dailymotion.com/video/x6agslv>), and is a gripping graphic animation of the events following a viral infection, in this case by an adenovirus. In other words, it is a 'story of a viral infection - the battle for the cell'. In summary: The story starts with a general introduction followed by the infectious event, a person walking past an infected sneezing individual and unknowingly inhaling an army of viral invaders (this part is not animated). This can lead to common cold symptoms or to more serious conditions such as fatal pneumonia (similar to COVID-19). The virus is a master of deception and hijacks the cell's inherent structures and processes for its own selfish ends - to build a new virus army.

In summary, the graphic account follows the viruses as they make their way into the upper respiratory tract of a new victim and attempt to make their way through his body's first defensive barrier, an opposing host of antibodies - special proteins that patrol the spaces between cells in search for possible invaders. They recognize the invaders and lock onto their protein coats to mark them for destruction by the massive white blood cells. Although many viruses are destroyed by this counter-attack, some make it through and head towards their target - individual epithelial cells in the upper respiratory tract. The film reveals the astounding detail and machinery of the cell, beginning with the intricate plasma membrane, the second major barrier for the virus. The film briefly shows how different molecules normally pass through the cell membrane (revision of earlier lectures), and then reveals how the viruses deceive the highly specialized receptors in the cell membrane and get taken into the cell through endocytosis. The cell is now heading for disaster. The storyline then considers the debate on whether viruses are alive or not - despite them behaving like living organisms (revision of earlier lectures), they do not technically qualify as 'living'. The viruses then enter the endosomes (sorting stations) of the cell where they are, as all other cargo, broken down through the acidic interior of this cell body. But, although some are destroyed, many escape and succeed in high-jacking some motor proteins that travel along the cell's microtubules - part of the cell's cytoskeleton. These motor proteins are powered by ATP, mostly produced in the mitochondria of the cell. These transporters literally carry the viruses to the nucleus. However, the nuclear pore complexes are too small for the virus to enter and a tug of war ensues between the motor proteins and the recognizing proteins of the nuclear pore complex, and as a result, the protein coat of the virus is ripped apart and the viral DNA is released to enter the nucleus of the cell. The film illustrates the DNA contained inside the nucleus - the blueprint for all the proteins and RNA of the cell. Unfortunately, the molecular machinery within the nucleus cannot distinguish the viral DNA from its own DNA, and therefore starts to transcribe the viral DNA into mRNA, thereby creating a blueprint for its own destruction. This is the first step to producing new viral proteins and therewith a new viral army. The newly created mRNAs leave the nucleus and return to the cytoplasm where the blueprints are read by mobile protein factories - the ribosomes. The viral proteins are constructed according to the genetic code and each one folds into a designated shape after which they are drawn back into the cell's nucleus. By now, the virus has taken complete control of the nucleus and normal cellular activities have come to a standstill. In a last desperate attempt, the cell sends out an SOS in the form of a vesicle containing fragments of the virus particles to the outside of the cell (by exocytosis - more revision of earlier lectures). This warning flags the cell as being infected. When this distress signal is noticed by patrolling white blood cells, an attempt is made to destroy the entire cell together with the invading viral army. If this attempt fails, the infection can and will continue to spread from one cell to another. The film goes on to depict the construction of the new virus army inside the nucleus while releasing proteins to break down the cell's nuclear envelope, as well as the cytoskeleton, causing the cell to collapse. By the time the nuclear envelope perishes and the hordes of newly constructed viruses erupt from the structure, the cytoplasm already resembles a wasteland of destruction. The viruses are now free to flood neighbouring tissues and cells, spreading infection as far as they go. Fortunately, the immune system adapted in the meantime and can now fight the infection with more precision. White blood cells accumulate in the area of infection and start destroying even healthy uninfected cells as a safety precaution. Moreover, neighbouring cells may commit suicide during this time to stop possible infection. In this epic battle, the whole immune system works together to stop the viral infection. Until the next time!

I realized that a number of the eukaryotic cell structures can be taught using the film: the cell membrane, endosomes and lysosomes, the cytoskeleton, motor proteins and vesicle transport, as well as the nucleus and nuclear envelope. The film also briefly touches on mitochondria. The remainder of the eukaryotic cell structures were covered in the following lecture.

For the lesson plan, the translation device as shown in Table 2 and Figure 3 was used. The 'core' content was identified for the lecture (Table 2A) - to teach the structures and processes of eukaryotic cells (PA+) using the usual PowerPoint presentation. Closely related content, known as 'ancillary', represented other cytology such as the structures found in prokaryotic cells. Both these categories fell under the greater target content of Cytology. Other content, such as the viral invasion depicted by the film, fell into the 'other content for other purposes; associated' category (PA-). Other knowledge beyond Biology falls into the 'other content for other purposes; unassociated' category. As far as the purpose of the lecture was concerned, the main aim was to teach the students the structures and organelles of eukaryotic cells and related Cytology (RA+). But in this case, there were also other purposes involved (Table 2B) - teaching the students about general virology and COVID-19 - the real-world situation influencing their current and future lives (RA-). As shown in Figure 3 and Table 3, the lesson plan was executed by shifting between the core content in the PowerPoint presentation and the virus invasion shown in the film - thus purposeful shifts on the autonomy plane to enact autonomy pathways for integrative knowledge building.

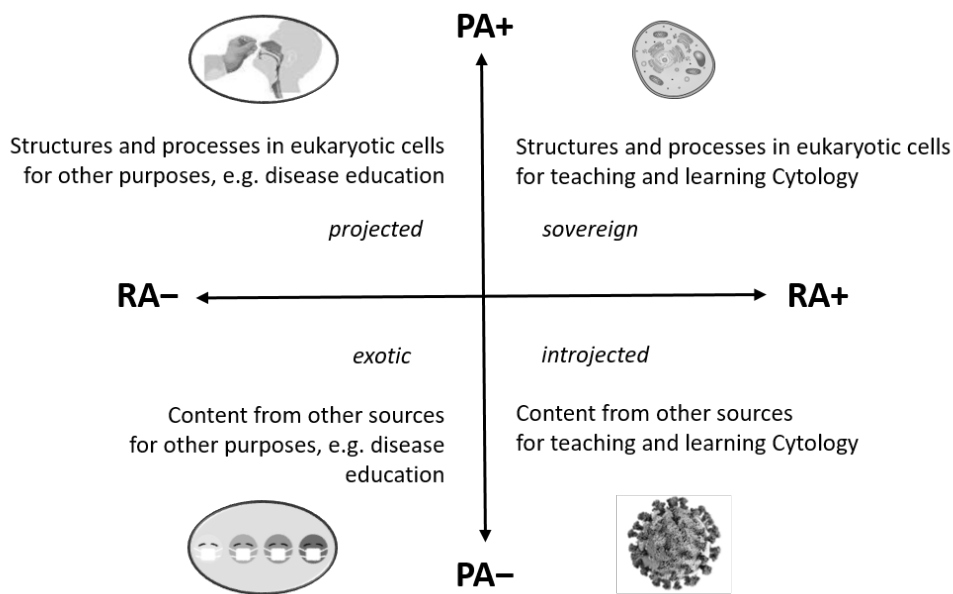


Figure 3. The Autonomy Plane for the Cytology Lesson

Since lockdown followed shortly after this lecture, and we had to move to emergency remote teaching and learning in a very short time, it was not possible to collect student feedback at the time. Now, more than a year later, one student was asked about her experiences of this lecture. She has given consent that her answers to the questions may be used in this publication, since she agrees with and supports this type of pedagogy. She has been recognized for her contribution under Acknowledgements.

Table 3. Coding of the Cytology Lesson

Source*	Content	Autonomy Code
A	<p>Introduction: In this lesson, we are going to look at a world that is smaller than you can ever imagine – the world of a cell. However, this is a story that is larger than the biggest of imaginations (the film), a story about viral infection that will reveal many of the complex structures found in eukaryotic cells.</p>	i
	<p>On Thursday March 5 2020, the National Institute for Communicable Diseases reported the first case of COVID-19 in South Africa. The patient was a 30 year old male who travelled to Italy just before. By now (middle March 2020), COVID-19 has escalated to pandemic status and continues to ravage Europe, especially Italy and Spain. COVID-19, caused by the novel SARS-CoV-2 virus (a new coronavirus), was first identified in December 2019 in Wuhan China (presumably earlier) and was thought to have originated at a seafood market in Wuhan. Genetic tests, however, indicated the source of the particular viral strain to be bats. But, no bats were sold or found at the market that was presumed to be the outbreak's epicentre. So scientists are still not sure which animal transmitted the virus. One possibility suggested by a number of studies, is the pangolin, an endangered ant-eating mammal. However, this could not yet be proven since the viruses obtained from sampling illegally traded pangolins were genetically not closely related to the SARS-CoV-2 virus (Nature). Another study implicated snakes sold at the market as the source of the virus, but experts have criticized these findings, saying that it is not even known if this virus occurs in snakes.</p>	e
	<p>To infect an animal or human cell, interaction between specific proteins on the surface of the virus particle and specific cell surface receptors of the host cell is required. The specificity of this interaction is responsible for the specific and limited host ranges of each animal virus. These cell surface receptors normally have specific cellular functions. However, they get hijacked by the virus and are thus literally fooled by thinking that they are involved in performing normal cellular functions. The virus gains entry through them by using a fake or counterfeit key (a protein spike). It then depends on the type of virus what happens next, but the influenza viruses, for example, are ingested by the cell through endocytosis, which then releases the viral sheath with the RNA inside the host cell's cytoplasm. Inside the cell, the virus then hijacks another cell system to progress on its journey to the cell's nucleus, the motor proteins moving on the cytoskeleton. And so they are literally driven to the cell's nucleus. Their aim is to release their genetic material into the nucleus, to replicate themselves.</p>	i
	<p>So, in this lesson, we are going to look at the cell membrane, the extracellular matrix (ECM), lysosomes, motor proteins, the cytoskeleton, the nucleus and nuclear envelope. We will see how a virus hijacks the cell's receptor proteins (ECM) to gain entry through the cell membrane, evade being destroyed by the lysosomes, and then hijacks the motor proteins to be driven to the nucleus. We are going to consider each one of these cell structures and the role they play in this invasion.</p>	s p

Table 3. Continued

Source*	Content	Autonomy Code
B	Inhaled from a sneeze, an alien army (an Adenovirus) is invading a victim's respiratory system. It can cause anything from a common cold to deadly pneumonia. The aim of the virus is simple: to breach a cell's defence mechanisms and reach its nucleus. Once inside, it can take control of the entire cell and reproduce!	e i
	The body's own immune system is the patient's first line of defence against the viral infection. Antibodies (Y-shaped proteins) identify the viruses as intruders. They lock onto the viral capsids, shuttle them together, making them a target for the white blood cells that destroy countless of them.	i
	Despite the immune response, many viruses make it through to the cell's surfaces. Here they face the next defence obstacle, the cell's membrane. Receptor proteins – there are many different types, some communicate with the ECM and with other cells, while others can bring entire cargos into the cell.	i s
	Some molecules can enter the cell via diffusion, e.g. water and O ₂ . Other molecules, such as glucose need to be taken into the cell via special protein pumps. However, larger cargo need special protein keys to bind to special receptor proteins to allow entry into the cell. The virus developed such a 'counterfeit key' – a protein spike through evolutionary processes. It binds to the receptor protein and is taken into the cell.	s i
A	The cell membrane : the phospholipid bi-layer containing many different membrane proteins. One such type are receptor proteins – some communicate with the ECM and with other cells, while others can bring complete cargos into the cell. They form part and communicate with the ECM.	s
	Membrane transport (active and passive transport) and bulk transport endocytosis (done in earlier sections but repeated again to show significance and application of earlier core concepts).	s
B	The virus' protein coat is a multi-layered cloak of deception and it carries a small piece of DNA – its ultimate weapon. The virus is a masterpiece of evolution and design. However, it cannot reproduce on its own, it needs to hijack parts of cells.	i
	All deliveries into cells first need to be taken to sorting stations, endosomes. These organelles break down large molecules and the viruses are about to be digested. The pH within these organelles are low due to special protein pumps in its walls bringing in atoms. The acidic environment breaks down the protein coat, first the virus fibers (spikes) which releases a special protein from within the virus that targets and breaks down the wall of the sorting station, releasing the virus particle into cytoplasm. However, many viruses are broken down and eliminated by these organelles.	s i
A	Lysosomes (endosomes): Human cells contain approximately 300 lysosomes. These are breakdown bodies (small membrane bound vesicles) – they contain more than 30 hydrolytic enzymes and break down complex molecules (e.g. proteins) to simpler ones. The interior is characterized by a low pH (± 5) due to high concentration of H ⁺ being pumped into the organelle. They form from budding off the Golgi complex and their enzymes are formed in the rough ER.	s
	Lysosomes are found in animal cells but not plants. They also digest old / dysfunctional organelles, known as autophagy. Lysosomes also play a role in phagocytosis, e.g. phagocytes.	s

Table 3. Continued

Source*	Content	Autonomy Code
B	Although the virus is surrounded by the bustling of cellular activities, it cannot move itself. It now needs transport to its target, the nucleus of the cell and it also needs to tap into the power supply of the cell – the mitochondria. Inside each mitochondrion, the food we eat and the air we breathe drives thousands of turbines that continually recharge billions of tiny batteries. It is really extraordinary that scientists believe that mitochondria were once simpler cells themselves, one was then swallowed by another cell, starting one of the greatest leaps in evolution - complex life.	i s
A	The mitochondria : These are the organelles where most reactions of cellular respiration occur. Energy-rich molecules (sugars and fats) are broken down to CO ₂ and H ₂ O by mitochondrial reactions with the release of energy (ATP). The mitochondrion is enclosed by two lipid bi-layer membranes. Outer - smooth and covers the outside. Inner - expanded by folds called cristae. The two membranes enclose the mitochondrial matrix. The ATP generating reactions occur in the mitochondrial matrix and cristae.	s
B	The virus now needs to hijack the machinery of complex cellular life. Many motor proteins (molecular haulage workers) await nutrients processed for delivery by the endosomes. Through evolutionary processes, the virus has evolved to be able to attach to the cell's motor proteins. This way, it can use the energy of the mitochondria. Once attached to such a motor protein, it is on its way to the nucleus. It has hijacked the cell's own transport system. These microscopic motorized 'legs' are a wonder of the natural world. They take over 100 steps per second. They may encounter obstacles on the way (the cytoskeleton) and they can only move in one direction. However, there is another type of motor protein that the virus locks onto – one that can travel in the opposite direction. And together, these motor proteins can navigate around most obstacles to the benefit of the virus.	i s i s i
A	The cytoskeleton : The shape and internal organization is kept in place by the cytoskeleton. This is an interconnected system of protein fibres that runs through the cytoplasm. Very well developed in animal cells - it supports the plasma membrane and helps with movement, inside the cell and of the cell as a whole. Microtubules (MTs) are microscopic tubes consisting of tubulin proteins (dimers) and function like scaffolding. They consist of 13 protein filaments arranged side by side. MTs can change their length and have a + and – end. Many are found in animal cells and radiate out from the centrosome. Play key functions: (1) Anchor the ER, Golgi complex, lysosomes, secretory vesicles and some mitochondria. (2) They provide tracks for dyneins and kinesins to transport vesicles from the cell interior to the plasma membrane and back. (3) They separate and move chromosomes during cell division. (4) They maintain the shape of animal cells. (5) They allow movement in animal cells e.g. muscle cells (myosins). Intermediate filaments (IFs) are fibres with an 8-12 nm diameter, consisting of intermediate filaments proteins. The fibres occur single, in parallel bundles, or in interlinked networks. IFs are tissue specific in protein composition. In animal epidermis, the nucleus is held in position by a basket shaped network of IFs made of keratins. Microfilaments (MFs) are thin protein fibres with a 5-7 nm diameter and consist of 2 polymers of actin molecules wound round each other. MFs transport nutrients, proteins and organelles in animal and plant cells. They are responsible for dividing the cytoplasm in cell division and movement (e.g. amoeboid movement).	s
	The motor proteins : myosins, dyneins and kinesins. They allow for movement and transport of molecules and organelles in cells (e.g. muscle cells) by pulling on microtubules or microfilaments. They use energy from ATP hydrolysis to 'walk' on the microtubules (kinesin and dynein) and microfilaments (myosins). Kinesin can only move towards the + end of the microtubules (thus towards the cell membrane), whereas dynein moves in the opposite direction, towards the – end, near the centrosome.	s

Table 3. Continued

Source*	Content	Autonomy Code
B	It only takes a single virus to take over an entire cell. A virus that was not tagged by antibodies also escapes the cell's proteosomes. But now, the virus needs to get into the nucleus to achieve its goal. It needs to take advantage of the cell's own mechanisms for its own selfish ends. At the heart of each cell lies the nucleus – a world of its own. Its surface is similar to that of the cell's membrane, but entry is regulated by different gateways. Across its surface, protein arms search for molecules to draw inside the nuclear pore. Billions of chemical messages and instructions pass through these gateways between the DNA and the cell, but only if the protein arms recognize them. The viral shell carries another counterfeit key. The protein arms lock onto the virus, but it is too large to fit through the gateway. The motor proteins reckon that they reached an obstacle and start to reverse. This pulling in opposite directions leads to the virus being pulled apart. It seems like the end for the virus, but in fact it is its final strike. Its single strand of DNA is carried through the gateway and into the nucleus.	i s i
A	The nuclear envelope : The nuclear envelope separates the nucleus from the cytoplasm. A network of protein filaments called lamins (a type of intermediate filament) lines and strengthens the nuclear envelope in animal cells. The nuclear pore and nuclear pore complex : Hundreds of nuclear pore complexes are embedded in the nuclear envelope. The nuclear pore complex is a large, octagonally symmetrical structure formed from many types of proteins called nucleoporins. Small molecules can pass through nuclear pore unassisted. Larger molecules e.g. RNA and proteins (cargo) are carried through by a transport protein acting as a chaperone. Proteins destined for the nucleus contain a 'tag' (a few amino acids), known as a nuclear localization signal. Special proteins in the cytoplasm recognize this 'tag', bind to the signal and move the protein through the nuclear pore complex.	s
B	Inside the nucleus of a human cell are approximately 23 000 genes. They code for thousands and thousands of biochemical molecules. That virus only has 40 genes, but it can still do extraordinary things. The virus is a masterpiece of design, continuously exploiting the cell's processes for its own deadly aims. The cell's own DNA machines have no way to tell the difference between its own DNA and the DNA of the virus. They start decoding the DNA code into instructions for the cell to act upon which are basically blueprints for the cell's own demise.	s i
A	The nucleus : Eukaryotic cells have a true nucleus and cytoplasmic organelles enclosed within a plasma membrane. The nucleoplasm is the liquid/semi-liquid substance inside the nucleus. Chromatin, a combination of DNA and proteins, fills most of the nucleus. There are many linear DNA molecules in the nucleus of eukaryotic cells. Each individual DNA molecule with its proteins, is known as a eukaryotic chromosome. Genes that code for most proteins occur in the chromatin, as well as the genes for the coding of RNA molecules. The nucleus contains one or more nucleoli - an irregular mass of fibers and granules. These structures form around the genes coding for the rRNA molecules of the ribosomes.	s
B	But the machines that convert the blueprints into proteins are in the cytoplasm outside the nucleus. In the cytoplasm, the instructions are met by hundreds of ribosomes (protein factories). They follow the instructions very accurately and start assembling viral proteins. Each protein is folded into a specific shape and has a unique function – the components of a new viral army. The new viruses will be constructed within the nucleus and the viral proteins are therefore drawn back into the nucleus. The virus has now taken complete control over the cell's nucleus.	s i

Table 3. Continued

Source*	Content	Autonomy Code
A	<p>Ribosomes: Ribosomal RNA is formed in the nucleus and combines with special proteins to form the ribosomal subunits. The ribosomal subunits then leave the nucleus through the nuclear pore complexes where they join mRNA molecules to form complete ribosomes. Ribosomes consist of two subunits – large and small subunits. Eukaryotic ribosomes are larger than prokaryotic ribosomes and contain 4 types of rRNA and 80 proteins. Eukaryotic ribosomes are either free in the cytosol or attached to membranes. Proteins made by free ribosomes in the cytosol remain there, pass through the nuclear pores into the nucleus or become components of mitochondria, chloroplasts, the cytoskeleton or cytoplasmic structures. Proteins that enter the nucleus become part of the chromatin, the lamins or remains in the nucleoplasm. Proteins made by the ribosomes attached to the nuclear envelope or the ER follow a special path to other organelles within the cell.</p>	s
A	<p>Conclusion: Eukaryotic cells are incredibly complex structures – they have many organelles who participate in a host of activities to perform their respective functions.</p>	s
	<p>Viruses are masters of deception and evolved over millions of years to outwit their host cells on many different levels. Today's lecture showed the eukaryotic structures and their role in a viral invasion.</p>	i
	<p>COVID-19 is in the process of taking over the world as we know it. However, now you know more about viruses and their ways and I hope that it will inform you to take care and precautions in the months to come.</p>	e

Table 2. The Translation Device for this Paper (Adapted From Maton & Howard, 2018) for Positional Autonomy (PA) and Relational Autonomy (RA).

PA	First Level		Second Level	
+	<i>Target</i>	First-year Biology content on the subject of eukaryotic cells	<i>core</i>	Cytology: The structures and processes in eukaryotic cells
			<i>ancillary</i>	Cytology: Other related topics, e.g. the prokaryotic cell
	<i>Non-target</i>	Other content	<i>associated</i>	Other Biology knowledge, e.g. Virology
			<i>Unassociated</i>	Other knowledge beyond Biology
-				
+	<i>Target</i>	For the purpose of teaching and learning Cytology - eukaryotic cells	<i>core</i>	Teaching and learning Cytology: The structures and processes in eukaryotic cells
			<i>ancillary</i>	Teaching and learning Cytology: Other related topics, e.g. the prokaryotic cell – pointing out the differences
	<i>Non-target</i>	Other purposes	<i>associated</i>	Using other knowledge, e.g. Virology for educating students about COVID-19
			<i>Unassociated</i>	Other knowledge beyond Biology for educating students about COVID-19 and other pandemics
-				

Discussion

The new amended Cytology lesson with the COVID-19 context, was conceptualized around the very graphic animation film about a viral invasion of a human cell. It has been shown that modern-day students are ‘wired to sophisticated, complex visual imagery’ and using visual forms in teaching would therefore be beneficial for learning (Rothman, 2014). Visual imagery has huge potential to connect people to real experiences and to improve performance in the learning process, and probably even more so when the scenario is playing out in real life too. Moreover, learning is not about creating more abstract mental representations, but rather about the ability of students to assimilate information in a manner that is meaningful to their own learning (Murphy, 2019). After all, humans have the ability to employ space when they create art, visual imagery and complex tools, it is therefore odd that relatively little attention has gone into human space competence when it comes to learning (Schwartz & Heiser, 2006). Jandhyala (2017) explained why visuals are so effective in the learning process: (1) Visual images are the most effective means to retain information in the long-term memory; (2) the human brain has the ability to process visual images and videos up to 60 000 times faster than text; (3) visuals can extend students’ abilities and capacity when it comes to absorbing, comprehending and analyzing new information; (4) powerful imagery has the power to create strong impressions and therefore long-term memories in students because visual information and emotions are processed in the same parts of the human brain; (5) interesting images and videos usually spark interest in students which impacts positively on their motivation for learning. The viral invasion animation film (visual imagery) was therefore an ideal engaging learning tool to incorporate into the lecture, as this comment from the student confirms:

‘As a visual learner, the graphic representation of cells, proteins and viruses helped me to understand the concept of cytology holistically, but also to understand some of the detail of how proteins function in a living system. I have thought back on that lecture many times because the material was suddenly tangible in my everyday life. I remember coming home to my father and telling him about this specific lecture. He wanted to watch the film just because of my enthusiasm.’

There is a fundamental shift in what modern-day students need to know (Daggett, 2016; Rothman, 2014). Not only do these students favour sophisticated, complex visual imagery (Rothman, 2014), they are also digital natives and accustomed to frequently accessing a vast body of knowledge instantly (Daggett, 2016). When it comes to their education, the focus of educators therefore needs to shift to applying this knowledge across disciplines to real-world predictable, but also unpredictable circumstances (Daggett, 2016). Bringing COVID-19 into Biology lectures was an intentional

instructional strategy which aimed to maximize the mental stimulation and engagement of these modern-day students – it involved life science fundamentals playing out in a critical current real-life situation. Moreover, at that point in time, it became apparent that the entire world knew very little about the novel virus or how to plan for managing the looming crisis. And, predicting the outcome of the threat would be extremely challenging for some time in the foreseeable future. The epidemic escalated from epidemic to pandemic – very few living individuals had ever experienced a similar situation. Understanding the fundamentals of the science behind the peril would empower students and challenge them to engage with the biology fundamentals for the foreseeable future. It was further very probable that research on this topic would skyrocket in the months and years to come, and setting the students up with an understanding of the cell biology involved, would virtually be ‘extending the curriculum’ for a much longer time into the future which is evident from this student feedback:

‘Including real-world problems and emphasizing that there are no current remedies or cures encouraged me to kick-start my problem-solving skills. I was thinking through the processes and variables mentioned in the lesson. I was studying and memorizing work without realizing it. More than a year later, I still think about that lecture and that particular video. I remember much of it. It helped me understand why we sanitize regularly and why we wear masks to curb the pandemic. Knowing the mechanisms of a virus so intimately has given me another chapter to the book of common sense.’

This approach was also supported by the Rigor/Relevance Framework developed by Daggett (2016) which explains that learning is optimized when students are required to engage in complex thinking (along Bloom’s Taxonomy), as well as the application of the knowledge to real-life situations (higher along the Application Model continuum) (Daggett & Nussbaum, 2008). The COVID-19 narrative gave students the foundation from which to think in complex ways and apply their knowledge to confront the unknowns of the situation and the future – and therefore fell into Quadrant D/Adaptation of the Rigor/Relevance Framework. Moreover, the topic was relevant to all students – no discrimination against race, gender, competence or background – everyone was and is still affected by the topic (the virus infecting cells).

Before incorporating COVID-19 and the film into the Cytology lectures, these usually contained only the theoretical fundamentals due to the high volume and complexity, which left the students without the bigger picture and insights into the vast body of real-life applications that exist. In LCT’s Autonomy terms, this approach left their understanding in the sovereign code – no Autonomy tours or pathways were taking place but rather a so-called ‘stay’ profile (Figure 2C), and therefore, no integrative knowledge-building. Their new Biology knowledge stayed insulated. And, although there is a vast field of applications for the Cytology concepts, especially in the field of health sciences, examples from this field are often far removed from most science students’ lived experiences. Also, if used, these examples were often briefly mentioned during the lecture (e.g. including Progeria to show the importance of the integrity of the nuclear envelope). Using such examples would have brought about fleeting movement on the autonomy plane, but these would have been relatively brief insignificant shifts without profound integrated knowledge-building taking place.

Maton and Howard (2021) bring an important issue to light – that, many science educators and education studies focus on ‘how students think’, while the forms of knowledge are often not considered. Most of these studies analyze knowledge by analyzing knowing, thereby ‘reducing knowledge to knowing and education to learning’. The different forms taken by knowledge are thus overlooked. Many scholars therefore call for the integration of specific disciplines, such as mathematics or biology, into the broader science when teaching, or as in this case biology and health science - thus, to integrate ideas from one body of knowledge with another second set of ideas from another body of knowledge. However, this requires teaching practices that can enable the integration of the different forms of knowledge in a meaningful manner. In this Cytology lecture we used knowledge from two disciplines (bodies of knowledge), Biology and Health Sciences. We showed that meaningful integration is essential and possible by using the Autonomy dimension of LCT – *autonomy codes, pathways and targets* – thus, purposeful shifts on the autonomy plane (Maton & Howard, 2021). By using the current and critical COVID-19 situation, combined with the film’s showcasing of a viral invasion, it was possible to teach not only the fundamentals of a range of cellular structures, but also extend the fundamentals into the way in which the virus ‘hijacks’ living cells, causing disease.

‘I remember vividly how transporter proteins latch on to cellular cargo and almost ‘walk’ toward their destination. The movability was astounding. Another clip helped me to understand how membrane proteins can let some substances through, but not others, with the help of a ‘key’ metaphor – viruses having the counterfeit, of course. The film was a very helpful learning tool because it also highlighted the solutions to the problems i.e., where the infection could fail and how we could make sure that the infection failed.’

As shown in Figure 4’s autonomy plane this strategy involved setting the stage, using the COVID-19 situation (first shifts) which introduced the students to the novel coronavirus, how it spread like wildfire wreaking havoc in China and Italy (big news at that stage), while introducing some basic disease education - starting in the introjected code, shifting to the exotic and then to the projected codes. Thereafter, moving towards the target content via the exotic and introjected codes (second shifts – Figure 4) by first teaching them how such an infection often takes place (another person coughing or sneezing onto you in a public setting) and how the immune system would react to such a viral invasion. Then moving between the target content - the structures of the eukaryotic cell in the PowerPoint presentation, and the viral infection

(other content; introjected code) and how it affects the cell's structures (shown in the film), and back to the target content again. Thus, from the sovereign to the introjected code and back for the greater part of the lecture time – repeated Autonomy return trips. At the end of the lecture (final shifts – Figure 4), we shifted again by relating the target knowledge back again to the novel coronavirus (introjected code). And finally finished off in the exotic code by talking about COVID-19, its expected spread across the globe and what we could expect in the months and years to come (exotic code).

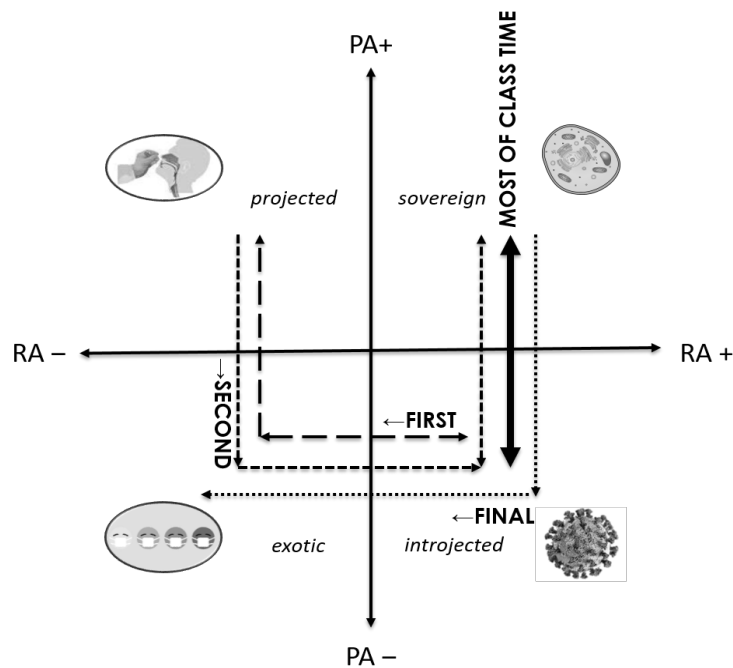


Figure 4. The Autonomy Pathways of the COVID-19 Cytology Lesson

The new teaching strategy enabled Autonomy pathways and therefore meaningful integration of the two bodies of knowledge. Moreover, the students were engaged and were gaining knowledge from both fields – the target Biology content and health care knowledge that they would be able to use in the months and years to come. Thus, integrated knowledge-building rather than learning insulated content knowledge.

Conclusion

COVID-19 was, and still is, a current and relevant real-world event that demanded and still demands students' attention. Bringing COVID-19, a current life-threatening real-world phenomenon, into the Biology classroom and curriculum was a fresh and innovative intervention. By 'Harnessing the beast' – COVID-19, a deeper level of curiosity and engagement was evoked among the students by creating perceptual arousal (Keller, 1987, 2010) – the students were visibly engaged. To bring current real-world events into higher education classrooms carry enormous potential for renewed motivation, relevance (Keller, 2010) and student engagement. All happenings may not be at the scale of COVID-19, but finding such contexts for academic theoretical content has the potential to make a world of difference to the way students perceive the subject content – either as relevant and important, or insulated knowledge which may not seem significant and useful to them. It is, however, important to integrate these bodies of knowledge in a cohesive manner that enables integrative knowledge building – academic knowledge that will be retained, and be recognized and applied across a range of contexts in future.

Recommendations

Using content from different bodies of knowledge to provide context for theoretical concepts can enable integrative knowledge building and help students to realize the relevance of such concepts. However, it takes effort to find relevant and engaging contexts and methods to enable integrative knowledge building – sharing of such good practices can help educators improve their pedagogy and promote student learning.

Limitations

It would have been ideal to collect data from more students about the learning experience and the intervention, but the lockdown events that followed shortly after this class made it impossible. However, it was apparent during the lecture (from observations) that the students were engaged and were very interested in the threat and how it infects and affects cells and their structures. The student who provided feedback confirmed this. Once we return to face-to-face teaching, I

would like to repeat this intervention but I expect that the keen interest would be less now since the novelty of COVID-19 has worn off since the time of the intervention.

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