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Exploring the electromagnetic spectrum with superheroes

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Abstract

The various radiation types that make up the electromagnetic (EM) spectrum are ubiquitous and highly significant in modern society. Detection of visible light by the eye facilitates sight, radio waves and microwaves are used in communication technologies, x-rays are used in medical imaging, and gamma rays are frequently employed in medical procedures. Although radiation plays a predominant role in daily life, many students have developed and retain misconceptions concerning EM radiation. These misconceptions could be addressed through the use of popular culture content such as superheroes in the classroom. In a number of superhero narratives, EM radiation plays a key role in the emergence or development of superpowers. In this paper, we outline three approaches for using superheroes to support the learning of the EM spectrum, and to potentially address key student misconceptions. In one approach we have designed a student worksheet based on Captain America and vita-rays, a fictional radiation type that plays a key role in his superpowers. The worksheet has been designed to instigate critical reflection on the part of the student, while allowing the student to apply their understanding of other forms of radiation.

1. Introduction

Since the advent of superhero comic books in the first half of the 20th century, the electromagnetic (EM) spectrum has been integral to many narratives with the powers of characters such as Bruce Banner, Supergirl, and Captain America attributed to their exposure to EM radiation. This exposure invariably led to irreversible biological changes that are associated with their abilities and, in some instances, permanent changes to their appearances.

In the real world, EM radiation is inherent to many aspects of everyday life. Visible light is crucial for the sensation of sight, microwaves and radio waves are emitted by innumerate mobile devices [1], and the detection of infrared (IR) radiation can be used in meteorology to determine cloud types or measure land and surface water temperature. These radiation types are non-ionising, and thus pose little or no health risks to a person. On the other hand, while ionising radiation such as ultraviolet (UV) radiation, x-rays, and gamma-rays can be used in medical treatments, they can also cause significant irreversible damage to biological cells and the DNA contained within, resulting in uncontrollable genetic modifications that could increase the risks of degenerative diseases.

In recent years, a number of studies have highlighted several misconceptions that students have in relation to electromagnetic radiation [2–7]. A questionnaire on radiation physics taken by 1246 Portuguese students at different education levels revealed that while most students had heard of radiation, worryingly, a number of students were not aware of natural radiation or differences between various kinds of radiation [2]. An additional concern raised by this study was that students could not differentiate between ionising and non-ionising radiation. In a subsequent study of 14–16 year old students in high schools in Austria, a number of misconceptions related to radiation were identified such as that all radiation is artificial and harmful, and light is visible while all other forms of radiation are invisible [3]. In addition, the study recommended that the positive uses of radiation be addressed in the classroom such as in advanced medical treatments.

It has been suggested that the use of media or newspaper content in the classroom can help address student misconceptions on radiation science [3, 5]. This can consist of both biased and unbiased media content and hence facilitate critical reflection and review on the part of the student. One content theme that could also be considered is the superhero genre given the popularity of both superhero films and literature among many audiences [8–10]. While film studios endeavour to portray a level of scientific accuracy through consultation with scientists and researchers, some scientific liberties are still taken for the sake of the narrative. Hence, radiation science has been somewhat depicted in an inexact and exaggerated manner, and it is conceivable that this content could instigate student misconceptions. However, the same content can also provide a stimulating platform for discussions on radiation science as will be outlined in this paper.

After briefly outlining electromagnetic radiation and differentiating between ionising and non-ionising radiation, we present two superhero exemplars where exposure to radiation has significance for their superpowers. We then present a classroom worksheet for students related to Captain America and a fictional type of EM radiation mentioned in the superhero films.

2. The electromagnetic spectrum

Before discussing the significance of radiation for specific superheroes, we define relevant terms and mathematical expressions. Figure 1 shows some of the different types of radiation that constitute the electromagnetic spectrum categorised by their wavelength, frequency, associated photon energy, and whether the radiation is ionising or non-ionising. The wavelength, which is usually denoted as λ, is measured in metres (m) and can be used to calculate the frequency f of a radiation in Hz using the formula $c = f\lambda$, where c is the speed of any electromagnetic radiation. From Planck's theory, the energy of a photon of a specific electromagnetic radiation is calculated from $E = hf$, where h is Planck's constant, and can be expressed in units of joules (J) or electron volts (eV), where $1\,\text{eV} = 1.6 \times 10^{-19}$ J. Finally, the different radiation are categorised as either ionising or non-ionising. Ionising radiation is any radiation that has sufficient energy to ionise or remove electrons from atoms or molecules in biological tissue, and in the process cause irreparable changes to the various components of a biological cell, including DNA. The ionisation potential is the energy required to remove an electron from the highest energy state and its value depends on the atom. For instance, the ionisation potential for a hydrogen atom is 13.59 eV, for a carbon atom is 11.26 eV, for an oxygen atom is 13.6 eV, and for a nitrogen atom is 14.53 eV [11]. These four elements together make up approximately 96% of the human body. Of all atoms essential for physiological functions, potassium has the lowest ionisation potential (4.34 eV). It is widely accepted that extensive exposure to ionising radiation can lead to cancer [12]. In the next section, we will outline how the superhero genre can be used to scaffold lessons on the electromagnetic spectrum using the aforementioned categorisations.

3. Superheroes and the EM spectrum

3.1. Superman and Supergirl: infrared, visible and ultraviolet radiation

Originally from Krypton, Superman and Supergirl represent two of the most powerful superheroes in DC Comics literature. Created by Jerry Siegel and Joe Shuster, Superman first appeared in *Action Comics* #1 in 1938 [13]. Supergirl, who was created by Otton Binder and Al Plastino, made her first appearance in *Action Comics* #252 in 1959 in the story 'The Supergirl from Krypton' [14]. Superman and Supergirl possess a plethora of powers such as flight, x-ray vision, impenetrability, superhuman strength, and heat vision. Although both have a human-like form, they are

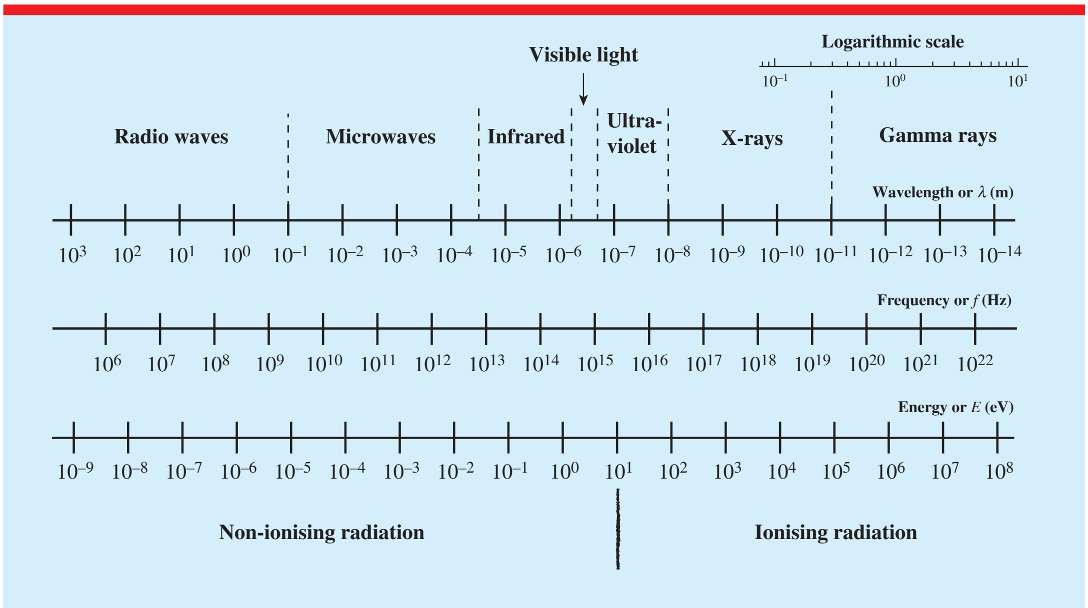


Figure 1. The electromagnetic (EM) spectrum showing different types of radiation in terms of wavelength (m), frequency (Hz), and energy (eV). In addition, the different types of radiation are categorised as either ionising or non-ionising.

unquestionably alien lifeforms with DNA that differs from human DNA.

The source of Superman and Supergirl's powers in the comic books has changed over the years. In the past, the powers were associated with the larger gravitational field experienced by inhabitants on Krypton in comparison to the gravitational field of the Earth. The current source of their powers in literature is related to the colour of the closest star. The Universe is filled with billions of stars, such as our Sun, with each star classified in terms of its luminosity, spectral type, colour (which is related to the temperature of the star), and whether it is a main-sequence star or another type of star. A main sequence star is a star that fuses hydrogen atoms into helium atoms with the production of excess thermal energy. For example, our Sun is a G2V type star where 'G2' indicates the spectral type and 'V' indicates that the Sun is a main-sequence star. In addition, the Sun is actually white when viewed in outer space. On the other hand, Krypton orbits the fictional star Rao, which is a red dwarf (M5V star) or a red supergiant depending on the specific DC literature, and is typically red in colour. When close to the red star Rao, Kryptonians such as Superman or Supergirl have no superpowers. However, on Earth, the closest star is the white Sun and, as a result, Superman and Supergirl have superpowers. A summary of the stellar classification used in astronomy, including the Sun and Rao, is presented in table 1.

Sunlight is composed of visible light, which is the radiation that the human eye can interpret for the sensation of sight, infrared (heat) radiation, and ultraviolet radiation, which can be divided into three different types of UV radiation: UVA, UVB, and UVC [15]. UVA radiation has a wavelength of 315–400 nm, photon energy of 3.10–3.94 eV, and is not blocked by the stratospheric ozone layer. UVB radiation has a wavelength of 280–315 nm, photon energy of 3.94–4.43 eV, and makes up approximately 5% of all UV radiation that reaches the Earth's surface [16, 17]. Finally, UVC radiation has a wavelength of 100–280 nm, photon energy of 4.43–12.14 eV, and is almost completely blocked by the stratospheric ozone layer. While UV radiation can generally be referred to as ionising, the UV radiation that reaches the Earth's surface, which is about 95% UVA and 5% UVB, has energies that are lower than the ionisation energy of the majority of atoms found in the human body. Therefore, only high energy UV, such as UVC, can lead to

Table 1. Stellar classification of main sequence stars in terms of spectral type, colour, surface temperature, and example stars. Note that the Sun is a G-type main sequence star, while Rao is a M-type main sequence star.

Spectral type	Colour	Surface temperature (K)	Sample star
O	Blue	30 000–50 000	10 Lacertae
B	Blue	10 000–30 000	Regulus
A	Blue	7600–10 000	Vega
F	Yellow-white	6000–7600	Procyon A
G	Yellow-white	5300–6000	The Sun (Our nearest star)
K	Orange	3900–5300	Alpha Centauri B
M	Red	Less than 3900	Rao (Krypton's nearest star)

Table 2. Effect of ultraviolet radiation or UVB (280 nm–315 nm), visible light (400 nm–800 nm) and infrared radiation (800 nm–0.1 mm).

Radiation	Human Tissue	Effect
Ultraviolet B (UVB)	Skin	Sunburn (inflammation), melanogenesis (tanning), immunosuppression, which can play a role in skin cancer (UVA can also cause cancer) [16]
	Eyes	Inflammation of the cornea; usually resolved within 48 h [16]
Visible light	Skin	Scattered, reflected and partially absorbed by different components of the skin [18–20]
	Eyes	Interacts with photoreceptor cells leading to chemical and electrical nerve impulses that are transmitted to the visual cortex in the brain [21]
Infrared (IR)	Skin	Strongly absorbed by water in the skin leading to sensation of heat
	Eyes	Heating of the lens and iris of the eye; possibly promote late onset age-related cataracts [22]

ionisation. For the human body, visible light, infrared radiation, and UVB have differing effects on the skin and eyes as outlined in table 2.

Just like the human population of Earth, the bodies of Superman and Supergirl interact with visible light, IR radiation and UV radiation from the Sun. For instance, their eyes appear to function just like normal human eyes in that light falling on the photoreceptors in their retinas leads to chemical and electrical impulses central to the sensation of sight. According to the superhero literature, white light emitted by the Sun excites the biological cells of the Kryptonians leading to their superpowers. Given the non-ionising nature of visible light, the scientific likelihood of this radiation being the cause of Superman and Supergirl's powers is highly dubious. It is more likely that their powers are associated with the UV component of sunlight, specifically the higher energy components such as UVB or UVC. In general, the amount of UV radiation emitted by a star depends on the temperature of the star with hotter stars emitting more UV radiation than cooler stars. This indicates that the Sun emits more UV radiation than Rao as it has a greater temperature (table 1).

For higher energy UV to suitably excite the cells in Superman and Supergirl's bodies, both will have to overcome the issue that UVC does not reach the Earth's surface as it is blocked by the stratospheric ozone layer. Thus, we propose the following method for Superman and Supergirl to 'charge' their superpowers. First, the UVB radiation temporarily excites their cells, giving them sufficient the ability to fly. In many DC comic book and films stories, both characters have been shown flying in outer space and show no ill-effects from flying above the protective ozone layer. Rather than damaging their cells, the higher energy UVC radiation could further excite their biological cells, and lead to the expression of their other superpowers. For human eyes, UVC would lead to inflammation of the cornea, but this does not occur for Superman and Supergirl. Instead, UVC may excite an additional photoreceptor in their eyes that can store the energy and release it at a later time as their heat vision. Superman and Supergirl could also interact with extreme ultraviolet radiation, which has wavelengths as low as 10 nm, associated photon energy up to 124 eV and can be emitted by clusters of galaxies [23]. Importantly, the atoms in Superman and Supergirl's bodies do not experience ionisation as a human would, and instead causes safe physiological changes to their bodies, which may be associated with the resilience of their bodies to genetic modification via ionising radiation.

Table 3. Misconceptions regarding UV radiation that can in part be addressed using Superman and Supergirl.

1.	All UV radiation can cause ionisation
2.	Just like visible light, the human eye can detect UV radiation and allow humans to have UV vision
3.	Different EM radiation interact with the human body in the same way, even if their wavelengths are close
4.	Dangerous or ionising radiation such as UV is only produced by artificial sources
5.	Natural radiation such as UV radiation produced by the Sun is completely safe

A number of misconceptions regarding ultraviolet radiation have been outlined in literature [6, 7, 24, 25] and are presented in table 3. The final two points may appear to be contradictory. However, some students may be aware that UV radiation is produced by natural sources such as the Sun and because of this they assume that the radiation is safe. Nevertheless, Superman and Supergirl provide stimulating exemplars that can be used to address the misconceptions provided in table 3 in the classroom environment. One common misconception in relation to dangerous radiation is that it can only be produced by artificial sources such as those created by humankind [1, 6, 7, 24]. However, the argument presented here is that Superman and Supergirl gain their powers from exposure to UV radiation, which is produced by a natural process such as nuclear fusion in the stars of the Universe.

3.2. Bruce Banner and the Hulk: gamma rays

Just like Superman and Supergirl, Bruce Banner, better known as the Hulk, is another character whose superpowers are associated with EM radiation. The Hulk was created by the Marvel Comics duo Stan Lee and Jack Kirby, first appearing in *The Incredible Hulk* #1 in 1962 [26]. During an atomic bomb test, Banner is accidentally exposed to gamma rays. Amazingly Banner appears unaffected and recovers from the exposure in hospital. However, when he becomes angered or stressed, Banner transforms into the Hulk, a green-skinned being with superhuman strength, increased stamina, and rapid regenerative abilities. In the Marvel Cinematic Universe (MCU), Banner acquired his powers through experimentation with gamma rays in the laboratory as he sought to replicate the super-soldier formula that created Captain America [27]. Unsurprisingly, Bruce Banner is an expert on gamma rays and his expertise is called upon in the 2012 film *The Avengers* to track down the Tesseract, which emits a gamma ray signature [28].

On the EM spectrum gamma rays have the shortest wavelength, typically less than 10^{-11} m, and hence the largest photon energy (figure 1). They can be produced from the radioactive decay of the nuclei of natural isotopes such as radium-226 (Ra^{226}) and uranium-238 (U^{226}), and synthetic isotopes created in nuclear reactors such as cobalt-60 (Co^{226}), which can produce gamma rays with photon energies of 1.17 MeV and 1.33 MeV. Gamma rays can also be produced in the detonation of atomic bombs, as Bruce Banner knows quite well, and from the interaction of cosmic rays with the Earth's atmosphere. Cosmic rays are high-energy elementary particles such as protons emitted in space by galaxies and rotating neutron stars or pulsars. Exposure to gamma rays can lead to the development of cancerous tumours in many parts of the human body such as the kidneys, brain, and thyroid [17]. However, gamma rays can also be used in the treatment of cancer [29]. In addition to treating cancer, gamma rays are also used in food irradiation with the aim of killing bacteria [30], medical imaging [31], detected for astronomical imaging by space telescopes [32], and in vehicle or cargo imaging inspection systems [33]. One can protect against gamma ray exposure using materials made from heavy nuclei such as lead.

Gamma rays are a form of ionising radiation, and thus detrimental for living cells, hence the motivation for using gamma rays in food irradiation. For the human body exposure to gamma rays can have many adverse effects and lead to permanent damage to cells, negatively affecting biological function such as protein expression and potentially promote the development of future cancerous tissue. There are a number of ways to

Table 4. Misconceptions regarding gamma rays that can in part be addressed using Bruce Banner/The Hulk.

1.	Low doses of gamma rays (less than 1 Gy) are harmless
2.	Illness due to gamma ray exposure can only occur if the dose is greater than 1 Gy
3.	Exposure to large doses of gamma rays will not lead to death. Bruce Banner was exposed to large amounts of gamma rays and he still survived
4.	Gamma rays are not a form of ionising radiation
5.	Gamma rays can only be produced by artificial sources such as synthetic elements created in nuclear reactors
6.	Gamma rays cannot be produced by natural sources

quantify exposure or the dose to ionising radiation such as the absorbed dose, the equivalent dose, and the effective dose. Here, we consider the absorbed dose, which is the energy deposited in a medium by ionising radiation such as gamma rays and is measured in units of gray (Gy) where $1\ \mathrm{Gy} = 1\ \mathrm{J\ kg^{-1}}$.

Negative biological effects of an absorbed dose can be classified as either stochastic or deterministic. Stochastic effects, such as cancer, can develop for absorbed doses of less than 1 Gy but can take decades to manifest themselves. However, deterministic effects such as skin reddening, permanent damage to reproductive organs, and acute radiation sickness can result from absorbed doses in excess of 1 Gy [34]. For doses over 15 Gy, permanent ulcers on the skin can result. In the comic books, it is difficult to ascertain the absorbed dose for Bruce Banner due to the number of factors associated with the exposure such as the size or energy released by the bomb, Banner's distance from the explosion, and local weather conditions on the day. However, in the 2008 film *The Incredible Hulk*, it is revealed that Banner was attempting to recreate in the laboratory the super-soldier treatment used to create Captain America by developing a serum that was activated by gamma ray exposure [27]. Thus he must have been able to precisely control the absorbed dose during experiments. Here, we presume that Banner's body is subject to an absorbed dose greater than 30 Gy, given the extent of the physiological changes he experiences when he transforms into the Hulk. In reality, early symptoms after such a gamma ray exposure would include severe vomiting, diarrhoea, and headaches as well as the onset of fever. Therefore, rather than surviving such an exposure and becoming the Hulk, Banner should have died within 48 h of hospitalisation.

Evidently gamma rays are much more dangerous than the UV radiation associated with the powers of Superman and Supergirl. Similar to UV radiation, it is possible to use the example of Bruce Banner and gamma rays to address a number of possible misconceptions with regards to gamma radiation. To date, no study has assessed student misconceptions associated with gamma rays. Table 4 provides a number of possible student misconceptions associated with gamma rays based on the misconceptions of other radiation types. For example, given that Bruce Banner survived a very serious gamma ray exposure, many students might wrongly assume that gamma ray exposure can never be lethal. This is an example of how scientific inaccuracies in popular culture could be adopted by students. In addition, just as for UV radiation, many students may assume that gamma rays can only be produced by artificial sources. Similar to using Superman/Supergirl for the motivation of learning objectives associated with UV radiation, Bruce Banner and the Hulk can be used to support lessons on gamma rays.

4. Classroom worksheet: Captain America and vita-rays

While the powers of Superman, Supergirl, and the Hulk can be attributed to real EM radiation, Steve Rogers was transformed into the super-soldier Captain America after controlled exposure to vita-rays, a fictional form of ionising radiation. Captain America was developed by Joe Simon and Jack Kirby and first appeared in *Captain America Comics* #1 in 1941. In the 2011 film *Captain America: The First Avenger* [35], Rogers undergoes an experimental military treatment developed by Abraham Erskine and Howard Stark to become a super-soldier. First, an experimental serum is injected into Rogers' main muscle groups, which immediately changes his cells. After the serum is administered, Rogers is saturated with vita-rays to stimulate growth in his muscles. In addition to transforming Rogers

In the 2011 film *Captain America: The First* Avenger, Steve Rogers becomes a super-soldier after he is injected with an experimental serum that changed how his cells react to radiation after which he is radiated with vita-rays, a fictional form of radiation.

You are a research scientist hired by Howard Stark and Abraham Erskine to evaluate Captain America's super-soldier treatment. Stark and Erskine want you to assess the effect of vita-rays on Captain America's body. In addition, they want you to estimate the properties of vita-rays such as the frequency, wavelength, and energy, and make suggestions for further applications of vita-rays.

1. List some of the changes to Steve Rogers' body after being exposed to vita-rays

____

____

2. Steve Rogers was treated with vita-rays in an isolated container such that Stark, Erskine, and their team were not exposed to vita-rays. What does this tell you about vita-rays?

____

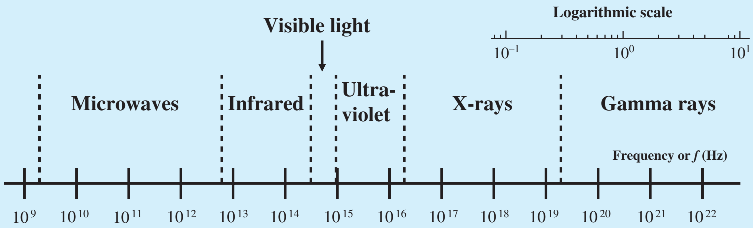
____

3. In your opinion, which type of radiation are vita-rays most similar to? Give reasons for your answer.

____

____

Using your answers, it is time to estimate the frequency, wavelength, and energy of vita-rays.



4. Mark the approximate frequency of vita-rays

5. Write down the frequency of vita-rays ______________ Hz

6. Categorisation of vita-rays based on frequency ☐ Non-ionising radiation ☐ Ionising radiation

7. Calculate wavelength in metres (m) of vita-rays

____

____

8. Calculate energy in eV of vita-rays

____

____

9. If vita-rays were real, how do you think they might used in modern society (besides in the creation of possible super-soldiers)?

____

10. If you have concluded that vita-rays are ionising, suggest measures to protect against over-exposure to vita-rays. If you have judged that vita-rays are non-ionising, support your conclusion.

____

Figure 2. Captain America/vita-rays worksheet.

into a person with peak strength, durability, and agility, he also gains an accelerated healing factor and the ability to survive in arduous temperatures, such as being frozen for almost 70 years in ice in the Arctic Circle.

The serum only modifies how Steve Rogers' cells respond to different types of radiation. Alone the serum is insufficient to facilitate the super-soldier transformation. Rogers is saturated with vita-rays meaning that his body reaches a point where it can no longer absorb any more radiation. However, vita-rays are a fictional radiation emitted by a fictional chemical compound nitramene. This prompts a number of questions on vita-rays such as its possible position on the EM spectrum and similarities with other forms of radiation, which can be utilised in the physics lessons on EM radiation.

We have developed a worksheet based on Captain America and vita-rays that can be used in conjunction with lessons on the EM spectrum. The worksheet is presented in figure 2. After briefly summarising how Steve Rogers becomes a super-solider in the 2011 film *Captain America: The First Avenger* [35], the student is assigned the role of a research scientist working with Howard Stark and Abraham Erskine. In the worksheet, the student is asked to evaluate the super-soldier treatment.

The worksheet is split into three sections. In the first section, questions 1 and 2 encourage analysis of the potential effects of vita-rays on the human body and the measures taken with regards to controlled exposure to vita-rays while in question 3, the student must formulate an opinion on the nature of vita-rays in comparison to other types of EM radiation. The second section (questions 4–8) is the numerical component of the worksheet. Based on their answers in the first section, the student can make an estimate on the possible frequency of vita-rays. Thereafter, the student must categorise vita-rays as non-ionising or ionising radiation and then calculate the wavelength and photon energy. Finally, using their answers on questions 1–8, the students are asked to reflect on the properties that they have assigned to vita-rays by proposing how vita-rays, if they really existed, could feasibly be used in society and suggest measures to protect against exposure to vita-rays, that is if the student has deemed vita-rays to be a form of ionising radiation. Included on the worksheet is the EM spectrum to allow students to compare the different forms of radiation, which is argued to help students explore the EM spectrum [7]. After covering the properties of visible light, infrared radiation, UV radiation, and gamma rays using Superman, Supergirl, and the Hulk, this worksheet can be utilised to motivate reflective and critical thinking on the part of the student, as a revision tool for EM radiation, and allow the students to 'think outside the box' on an interesting and stimulating topic from popular culture.

5. Discussion and conclusions

In this paper, approaches for the use of the superhero genre in support of learning objectives and classroom activities on the electromagnetic (EM) spectrum are presented. Thanks to the films of the Marvel Cinematic Universe and the films and TV series based on DC Comics literature, most students would be familiar with characters such as Supergirl, the Hulk, and Captain America. The focus of this paper has been on ionising radiation such as ultraviolet and gamma-rays, which can be strongly linked to the superhero narratives of Supergirl and the Hulk respectively. Using these characters we have highlighted the negative aspects of exposure to ionising radiation. Unlike these characters whose superpowers are partially dependent on high doses of ionising radiation, an ordinary person would be adversely affected by such a dose. For instance, UV-B radiation can cause inflammation of the cornea and play a role in the development of skin cancer while gamma-rays can interfere with many biological processes such as protein folding and potentially lead to cancer. In section 4, a worksheet based on vita-rays, a fictional form of radiation that are central to the Captain America origin story, is presented. The worksheet comprises of three sections: initial analysis of vita-rays, numerical calculations associated with vita-rays, and critical reflection on the properties and potential use of vita-rays (if they ever came into existence). The worksheet is designed to encourage the student to think laterally about the EM spectrum in a stimulating manner with reference to Captain America. For brevity, the topic of this paper has been limited to the electromagnetic spectrum. Elements of the content overlap with concepts in particle physics, which is a topic that will be considered in a future paper.

In previous articles on the use of superheroes in the classroom, we have also considered how superheroes can prompt reflection on responsible innovation in science such as advanced materials [36], invisibility devices [37], and implant technologies for the eye [21]. In addition, superheroes can also raise awareness with regards to state-of-the-art developments in other fields of science and engineering [38–40]. Evidently, developments in new medical treatments, manufacturing processes, and modern social technologies such as mobile devices that depend on ionising EM radiation can be used to stimulate critical reflection and classroom discussions with students. Pertinent questions in relation to new technologies based on an ionising EM radiation may include:

(i) What protective measures need to be put in place for the use of ionising EM radiation in new technologies?
(ii) How can physicists work with innovators and designers to ensure the safe use of the technology and management of the ionising radiation?
(iii) Given the possible dangers of over-exposure to ionising EM radiation, should this technology be introduced?

The worksheet and the supplementary materials in this paper have been developed for use by educators in the classroom. To facilitate this further, we wish to collaborate with interested educators on the effective implementation of this resource in the support of learning on the EM spectrum and associated concepts. In particular we would like to address a number of questions such as:

(i) Does the worksheet on vita-rays prompt constructive critical reflection on the part of the student?
(ii) Is this resource valued by the student and the educator?
(iii) How do the student answers at varying education levels affect the misconceptions on radiation outlined in previous studies?

Thus, we urge educators to make contact with us with regards to the implementation of this superhero resource in the classroom that could form the basis of an investigation on the effectiveness of these materials.

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