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Anti-Satellite Weapons: A Case Study

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Summary

The increasing use of anti-satellite weapons has made the weaponization of space more and more evident in recent years. More and more countries are placing military assets in space and hence many countries are developing anti-satellite technology. However, the consequences of this situation are more dire that one would imagine. The global economic and political stability might become victim to this underlying conflict and strife for power. The increasing amount of space debris, once it crosses a certain threshold, just might turn the space around the earth into a junkyard, making humanity's future space aspirations just a dream.

Hence, there is a need to strike a right balance between maintaining the sustainability of the space environment as well as maintaining global peace without compromising the national security of any country. This case study will discuss how this can be achieved by having a global body to manage humanity's space affairs.

Contents

1 Introduction

Human activity in outer space can be categorised into scientific exploration, navigation, communication, meteorology, remote sensing, defence, etc. In this case study, we will discuss more about the "defence" activities in space, in context to the increasing militarization of weaponization of space and its ethical, environmental, political and economic consequences.

The era of humans in space began during the cold war, with the launch of the first man-made satellite Sputnik-1 in 1957 by the Soviet Union. In 1958, the USA launched Explorer-1. However, along with launching new satellites, these countries began developing anti-satellite technology as early as 1959. This fueled a new struggle amongst these global superpowers which was popularly termed as the "space race". The space race brought about revolutionary advancements in human society in terms of scientific advancement, welfare and globalization, but the fact must not be neglected that this was again another means for the countries to demonstrate their might and gain the upper hand in the conflict.

Most countries around the world appear to be very keen on achieving such technology to gain military advantage, as "space" being the "new high ground" of warfare. Surveillance, navigation and communication satellites play a vital strategic role in military activities. Such satellites are commonly referred to as military satellites. Such satellites have propelled modern warfare into a new era, where capable countries have gained ultimate advantage in the battlefield of information gathering. All this has compelled nations across the globe to develop anti-satellite technology to destroy or disable enemy satellites in the interest of their own security.

1.1 Anti-Satellite Weapons

Anti-satellite weapons play a crucial role in defence against space-based adversaries. These weapons are used to destroy or disable enemy satellites in orbit. This technology can also be used to intercept ballistic missiles with potential nuclear warheads.

The early development of such technology began in the late 50s with the USA's attempts to develop anti-satellite weapons. The Soviet Union followed by initiating their own anti-satellite program in the early 60s. Currently many countries possess anti-satellite technology to at least a considerable extent. But only a few countries such as the USA, Russia, China and India are capable of destroying a satellite with a physical attack.

1.1.1 Kinetic Anti-Satellite Weapons

Anti-satellite weapons which launch a physical attack on the satellite in order to destroy it, are termed as [1] kinetic weapons. These types of weapons are the most destructive and produce a large amount of space debris. The kinetic weapons can be further categorized based on the used technology into: direct ascent and co-orbital weapons. Direct ascent technology is utilized in ground-based weapons that are launched into space to directly intercept the target satellite. These weapons are launched on a rocket and may sometimes detonate into a fragment cloud before they hit the target to increase the rate of success. This type of weapons have a drawback, as they are vulnerable to the target satellite's early warning system. Whereas, co-orbital technology is used to place the anti-satellite weapon in the same orbit as the target satellite and manoeuvre towards the satellite to strike. These types of weapons can also sometimes be detonated into a fragment cloud before they hit the target, in order to increase the success rate. Contrary to direct descent weapons, the co-orbital weapons are easy to camouflage from the enemy satellite which again increases the success rate of the mission.

Again it must be noted that, the kinetic energy weapons are most destructive and generate a tremendous amount of space debris.

There has been no occasion of this type of weapons being used in actual warfare, but several tests have been conducted over the span of half-century by countries such as the US, Soviet Union/Russia, China and India.

1.1.2 Non-Kinetic Anti-Satellite Weapons

Unlike kinetic weapons, non-kinetic anti-satellite weapons do not employ any kind of physical attack on the target satellite. These types of weapons make use of different electronic interference techniques to disable the target satellite or to misguide or deceive the enemy receivers.

The interference techniques [1] used in this type of technology are generally jamming, blinding, meaconing and spoofing. When the target satellite's signals are disrupted by some type of interference, it can be termed as jamming. Blinding techniques utilise lasers in order to overwhelm or disable or even sometimes permanently blind the target satellite by damaging the onboard sensors. The lasers used for this task are low-powered lasers, however, there has been ongoing ideology to make use of high-powered lasers that could potentially destroy the whole structure of the satellite. This might increase the risk of debris creation.

Meaconing is a technique of intercepting an enemy signal and rebroadcasting it to the enemy with incorrect information. Whereas spoofing is the method when a new false signal altogether is sent to the enemy making it seem as if it was broadcasted by the satellite. This is usually done to deceive or mislead the enemy.

The non-kinetic weapons pose a very low risk of debris creation compared to the kinetic ones.

Also it must be noted that this is the type of anti-satellite technology that is actively being used in the current modern warfare.

1.2 Space Debris

Any unwanted objects in space around the earth such as non-functional satellites, abandoned launch vehicle stages, other mission-related junk and fragments are all termed as space debris or space junk. The mission-related junk includes objects released from spacecraft fairings of the launch vehicle. Natural objects such as meteoroids and even micro-meteoroids can also be classified as space debris. This debris varies in sizes, ranging comparable to the sizes of a sand grain to a football field. Debris in size greater than 10 cm is traceable and is catalogued by many government and private space agencies. Debris smaller than 10 cm cannot be traced and is estimated to be in the amount of hundreds of millions. According to the European Space Agency [17], more than 36000 pieces of traceable debris are in orbit around earth.

[2] Space Debris poses a serious hazard to all kinds of spaceflight missions. And not just that, but the space debris indirectly poses a huge threat to the modern human society which is greatly dependent on satellite technology in every aspect of life. There have been many instances to this date when the International Space Station and other satellites had to carry out extra manoeuvres to avoid a collision course with orbital debris. The small untraceable debris at a very high momentum can also cause serious damage to spacecraft if any critical component is hit. Because of the untraceable nature of such debris, it is very difficult to take protective measures against such events.

If a satellite gets destroyed by space debris, a tremendous amount of money will be needed to be spent just to restore that satellite's service. Also, because of the hazardous nature of increasing amounts of space debris, the spacecraft would need to shield its critical components and carry excess fuel for extra manoeuvres to avoid space debris. This will affect the cost of the mission.

In events such as kinetic anti-satellite weapon tests, enormous clouds of debris are created and such clouds, due to earth's gravity and series of inter collisions between the debris objects can scatter into different orbits at variable altitudes. This can expose satellites around that altitude to serious risk.

2 Evaluation

2.1 Capable Countries (Stakeholders)

Many countries nowadays possess anti-satellite technology in at least one form or another. But the most destructive kinetic anti-satellite weapons have been tested by only a handful of countries. The USA and Soviet Union began developing and testing during the cold war, whereas China and India tested such weapons in the 21st century.

2.1.1 USA

The USA was the first country to attempt an anti-satellite test in September 1959. After failure in the first attempt, the US successfully tested [3] the anti-satellite interceptor 'Bold Orion' in October 1959. Over the span of two decades several tests were carried out, most of them successfully passed within the kill radius but resulted in failure. It must be noted that none of these tests created space debris.

[3] In September 1985, the USA conducted their first successful destructive test of the interceptor 'ASM-135' on the target satellite 'Solwind'. This test resulted in creating 285 pieces of trackable

debris in orbit. After this test, in 1986, the US tested its co-orbital anti-satellite weapon 'Delta 180 Payload Adapter System' which targeted 'Delta 2 R/B'. This test created 16 pieces of debris in orbit.

Following these tests, the USA and the Soviet Union decided to stop destructive anti-satellite tests to control space debris and prevent further escalations in the conflict between two countries.

However, after two decades, in 2008, the USA resumed their anti-satellite testing and tested the 'SM-3' interceptor by destroying the target satellite 'USA-193', thus creating 174 pieces of space debris. This test raised some criticism in the media. According to an article in Reuters[4], "...the test has raised fears of a new arms race in the heavens and increased tensions on Earth."

It must be noted that all debris generated from the USA's anti-satellite programme have all been de-orbited and burned out into the atmosphere.

2.1.2 Soviet Union/Russia

The Soviet anti-satellite [5] programme was named 'Istrebitel Sputnikov' which directly means 'Destroyer of Satellites'. The Soviet Union focused on co-orbital technology and began their testing in 1963. They developed seven interceptors and among them five have been successfully able to intercept the target. October 1968, Soviet Union tested its first destructive anti-satellite test, the target satellite 'Kosmos 248' was attacked twice by interceptors 'Kosmos 249' and 'Kosmos 252'. In 1970 and 1971, the Soviet conducted three more destructive anti-satellite tests, thus creating 292 pieces of debris in total.

From 1976 to 1982, the Soviet Union conducted around ten anti-satellite tests, out of which four tests were destructive and created around 300 traceable pieces of debris. Later in 1993 these tests were stopped.

Modern Russia started its anti-satellite programme 'Nudol' in 2014. This programme was allegedly stated to be non-destructive. This program focused on using direct ascent technology. Recently in November 2021, Russia conducted the ASAT test by destroying one of its decommissioned satellites called 'Kosmos 1408. It was criticised at a global level and considered a very irresponsible attempt as it generated over 1500 traceable debris and over hundreds of thousand small fragments.

An Financial Times' [6] article on Russia's latest test stated that, "Russia's anti-satellite test is a wake up call to mankind" further they added "Without better regulation of space, we risk turning Earth's celestial neighbourhood into a junk yard". According to [7] U.S Army Gen. James Dickinson, US Space Command commander, "Russia has demonstrated a deliberate disregard for the security, safety, stability, and long-term sustainability of the space domain for all nations."

2.1.3 China

China [8] started its anti-satellite campaign in 2007 as they destroyed their weather satellite 'FengYun 1C' by using direct ascent technology. This test was stated to be the most destructive test ever attempted as it caused over 3500 traceable debris and over 2500 among them are still in orbit. Small amounts of debris were over 150,000. These debris are estimated to remain in orbit for at least 15 years. These debris can cause very moderate to serious damage to other spacecraft.

According to [9] Space.com, "The satellite's destruction is now being viewed as the most prolific and severe fragmentation in the course of five decades of space operations." According to [10] Sky News "International Space Station being forced to swerve to avoid Chinese satellite junk" further they added "The problem has escalated since a Chinese anti-satellite test in 2007 created thousands of pieces of dangerous debris."

2.1.4 India

India was the latest addition in the destructive anti-satellite weapon testing countries. In March 2019, [11] India destroyed its experimental imaging satellite 'Microsat R' with direct ascent technology interceptor 'PDV-MK II'. This test was called 'Mission Shakti'. 'Shakti' literally means 'Power' in Hindi. The interceptor 'PDV-MK II' which was used to attack the satellite was originally a ballistic missile interceptor. [12] This test created around 129 traceable space debris. It was stated that this debris will perish in a few months, but around 126 pieces of debris are still in orbit. Because of this, the test was globally criticised.

According to NASA's Administrator Jim Bridenstine, [13] "That kind of activity is not compatible with the future of human spaceflight that we need to see happen." He also added that Indian anti-satellite test debris put the International Space Station at risk, calling the situation a "terrible, terrible thing."

2.2 Destructive Anti-Satellite Tests: Space Debris Analysis

Table 1 – Space Debris Data from Destructive ASAT Tests

Stakeholder Country	Test Date	Targeted Object	Interceptor	Technology	Traceable Debris Created	Amount of Debris Re-entered	No. of Debris Still in Orbit	Final Object Re-entry Date	Lifespan (in years)
Soviet Union	20/10/1968	Kosmos 248	Kosmos 249, Kosmos 252 (IS)	co orbital	252	173	79	still in orbit	53.14
Soviet Union	23/10/1970	Kosmos 373	Kosmos 374, Kosmos 2375(IS)	co orbital	147	112	35	still in orbit	51.13

Soviet Union	25/02/1971	Kosmos 394	Kosmos 397 (IS)	co orbital	117	72	45	still in orbit	50.79
Soviet Union	12/03/1971	Kosmos 459	Kosmos 462(IS)	co orbital	28	28	0	04/04/1975	3.34
Soviet Union	17/12/1976	Kosmos 880	Kosmos 886 (IS)	co orbital	127	69	58	still in orbit	44.9819
Soviet Union	19/05/1978	Kosmos 970	Kosmos 1009 (IS)	co orbital	71	7	64	still in orbit	43.53
Soviet Union	18/04/1980	Kosmos 1171	Kosmos 1174 (IS)	co orbital	47	43	4	still in orbit	41.64
Soviet Union	18/06/1982	Kosmos 1375	Kosmos 1379 (IS-P)	co orbital	62	4	58	still in orbit	39.47
USA	13/09/1985	Solwind	ASM-135	direct ascent	285	285	0	09/05/2004	18.67
USA	05/09/1986	Delta 2 R/B	Delta 180 Payload Adapter System	co orbital	16	16	0	31/10/1986	0.15
Soviet Union	26/12/1994	None	Naryad-V	co orbital	27	3	24	still in orbit	26.94
China	11/01/2007	FengYun 1C	SC-19	direct ascent	3527	651	2876	still in orbit	14.89
USA	20/02/2008	USA 193	SM-3	direct ascent	174	174		28/10/2009	1.69
India	27/03/2019	MicroSat-R	PDV-MK II	direct ascent	129	126	3	still in orbit	2.67
Russia	15/11/2021	Kosmos 1408	Nudol (14Ts03)	direct ascent	1500			still in orbit	
					6509		3246		

Table 1 shows [14] the data on 15 kinetic anti-satellite weapon tests that have happened throughout history which have caused a huge number of debris. The amounts of debris shown in this table only represent traceable space debris.

According to the European Space Agency [17] there are over three hundred million pieces of debris in orbit which are in small fragments. Around 36500 debris are in larger sizes which are more than 10 cm. Over half a million debris are there which are in the size of 1 to 10 cm. Among these traceable debris there are over 6500 debris generated by Anti-Satellite weapon tests. And among them around 3246 debris are still in orbit.

Space debris created from anti-satellite tests usually form a cloud of debris pieces, and for any spacecraft passing through such clouds can easily face extremely hazardous situations, where manoeuvres might not be enough to protect itself from being hit. Such clouds of debris consist of both large and small fragments of debris scattered randomly.

2.3 Consequences

The anti-satellite tests done by countries have all resulted in serious criticism by other countries. The act of testing such weapons might be only for displaying military and technological prowess, but by other countries, it might get misinterpreted as an act of aggression.

One of the significant consequences of these tests is the beginning of a new 'arms race' in space. Above mentioned countries have developed their anti-satellite weapons and many more countries are now developing such weapons. Such a situation is fueling the struggle to attain space combat capabilities in many countries.

Such a situation might result in global destabilization. And hence the existing tensions between countries may intensify further more.

Another most significant consequence of these tests is space debris which has been discussed above. Once a satellite is being destroyed in orbit, it immediately generates debris of varying sizes. If these debris hit other satellites, this might end up creating even more deris. Once the number of space debris crosses a certain threshold, there is a possibility of causing a cascade effect in the future. This potentially puts multiple satellites in close proximity to be destroyed. Satellites play a very vital role in the modern world and everyday human life. Destruction of a satellite can cas serious economic and logistic problems which might result in daily human activities coming to a standstill. Loss of communication or navigation or meteorological or remote sensing satellite of any certain country can result in loss of the country's important strategic or business asset, which can result in tremendous economic loss.

2.4 Review of Existing Guidelines

As discussed previously, anti-satellite weapons have not been used in any kind of warfare yet. But there are the possibilities of global destabilisation and it can lead to conflict.

The United Nations [15] published some guidelines and principles for outer space. In article 4 of Section A in Part 1 of United Treaties and principles on outer space, UN office for outer space affairs suggested "States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner. The Moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military maneuvers on celestial bodies shall be forbidden."

United Nations Institute of Disarmaments Research (UNIDIR) [16] has three recommendations.

- No Debris
- Low Debris
- Notification

'No debris' means countries should not conduct destructive types of anti-satellite tests or alternatively any test conducted must not create space debris. 'Low debris' suggests if a test is to be conducted, the amount of debris created should be kept at a minimum. Such a low amount that it should perish from orbit within a week. Notification is self-titled and can be defined as if a country needs to do an anti-satellite test, then they should inform other countries or all official global bodies to avoid misinterpretation.

The above guidelines indicate to use these tests for peaceful purposes. But these are just principles or some sort of guidelines. These are not laws. So, if a country would do an anti-satellite test they are not liable to follow any of these.

2.5 Possible Alternative Decisions

There could have been many different ways the situation could have been different from what it is today. Following are some possible alternative decisions the stakeholders could have made to lessen the intensity of consequences we must face now:

- Regarding outer space around the earth as a limited resource, given the humongous number of satellites we launch into space.
- Having the foresight that the number of debris being generated might cause severe consequences to humanity's future in space.
- After one successful test of a kinetic anti-satellite weapon, the stakeholders could have chosen not to carry out any more tests.
- Relying more on non-kinetic technology instead of kinetic technology for anti-satellite weapons.
- Similar to nuclear weapons, anti-satellite weapons could have been strictly monitored and controlled by a global body such as the United Nations.
- Instead of only creating guidelines, the United Nations could have created treaties to control the use of destructive anti-satellite weapons.
- When testing the weapons, the stakeholder countries could have intercepted the target object in a trajectory that could have reduced the debris creation.
- When testing the weapons, the stakeholders could have used a calculated trajectory and impact angle to propel the debris towards the atmosphere for them to burn out faster.
- When testing these weapons, the stakeholders could have targeted specific coordinates in space instead of an actual satellite target.

3 Solutions

It is a very tough dilemma to choose between the country's national security or sustainability of the space environment. But if in search of a practical solution, there can only be a middle path where military assets are kept being used for peacekeeping purposes in such a way that sustainability of the space environment is maintained.

There are some points that can be suggested here:

- In all previous discussions, it is mentioned that global bodies have suggested and recommended some guidelines. But there have to be some strict laws instead of these guidelines. If there are not any strict laws then countries tend to behave irresponsibly and more disorder will arise. If not any international laws, then treaties or agreements might give positive results.
- There has to be a global body who controls and regulates space activity. The United Nations Office for Outer Space Affairs might be a good candidate for this task.
- Space debris management has a vital role. Like the United Nations Institute of Disarmaments Research recommendations, any country's first and foremost agenda has to be that the test does not create any debris or creates low debris. If a country creates debris then they must have some strategy to manage or remove it from space orbit. But in the end it is everyone's responsibility to maintain the space environment sustainable and peaceful.
- Space traffic control is crucial. There are over 2000 operational spacecraft and a huge number of small and large sizes of debris in lower earth orbit. Chaos and discord is increasing with these spacecraft and debris. To reduce that, there should be a centralized administration system like discussed above, a global body that keeps the ecosystem in control and informs tester countries when and where they should conduct their space activities. If the lower earth orbit is full of spacecraft and debris, the country will get information so that they can put a hold on their project and wait for the orbit to clear. This type of architecture will help to create a valuable space ecosystem.

Hence, given the importance of space debris management, we would like to propose a framework to deal with these issues as follows:

3.1 Space Debris Management Framework

To minimize the space debris, the framework can be divided into two categories: prevention and removal of debris. Taking into consideration the efficiency of this task, prevention is definitely the better option of the two.

A. Prevention

New precautionary measures should be in place to minimize debris creation such as follows:

- Space debris should be tracked more actively and accurately.

- ‘None or minimal amount of debris’ should be a part of the requirement specification of a space mission.
- Reusable spacecraft and launch vehicles should be used as a norm.
- Mission-related debris should be minimized.
- For Low Earth Orbit satellites, the satellites closing their end of life should be brought closer to the atmosphere for them to re-enter and burn out as soon as possible.
- For satellites approaching the end of their lifetime in high altitude orbits, the fuel tanks should be emptied and the batteries should be discharged to prevent explosions.
- Mechanisms to prevent explosions should be included in the satellite design.
- Non-kinetic anti-satellite weapons should be prefered over the kinetic ones
- While testing kinetic anti-satellite weapons, the tests should be carried out in Low Earth Orbits, and the trajectory of the inceptor and angle of impact should be calculated to minimize space debris and propel all space debris towards the atmosphere.

B. Removal:

The removal of space debris is of uncertain feasibility. The current technology might not be an issue, but the economical factors might be the biggest hurdle in achieving this task. However, developing a long term framework model can be helpful in the future. Following are some proposals for the removal of space debris from orbits:

- The largest concentration of space debris is closer to the polar region, therefore the first priority shall be to remove debris from this area.
- Altitude-wise, the greatest concentration of space debris concentration is highest between the altitude of 800 to 1000 km [17]. Therefore, debris from this altitude should be given priority for removal.
- Different techniques could be utilized to remove debris from orbits, such as, using a specially designed net to catch the debris, or a clamping mechanism to catch the debris.
- But another technical challenge while debris removal might be the momentum of the debris, which makes it very difficult to catch them, unless the catching device reduces the relative velocity between the debris piece and itself.

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Student Self-reflection on performance

All students must complete the following sections for every piece of work they submit using this template. The aim of this is to help you use feedback more effectively to improve your marks and your skills as a professional engineer. This section is not formally marked, but your tutor may use it when discussing your work with you.

Describe how you have used AT LEAST ONE of the following sources of information to improve this piece of work: 1.) (PREFERRED) Feedback from previous assignment(s). This can be from the same module or from a previous module or previous year of study (e.g. comments from 1st year lab formal reports should be used to help improve your 2nd year lab formal reports). 2.) The marking criteria or rubric provided for this assignment. 3.) The Department Technical Writing Handbook for Students.
As a student, I find that having coursework to do in the form of assignments helped me keep up with my studies. The whole process of solving the assignment helped gain a lot of knowledge and deeper understanding of the topic. The assignments on MATLAB and systems engineering components from module EG7010 were very helpful to gain more knowledge. - Shreyash Hoval (skh26)
Are there any aspects of this work that you would specifically like the marker to comment/or advise on? For example: "I wasn't sure if my figure formatting looked professional and would appreciate feedback on this aspect"
Student to add text here…

Describe how you have used AT LEAST ONE of the following sources of information to improve this piece of work: 1.) (PREFERRED) Feedback from previous assignment(s). This can be from the same module or from a previous module or previous year of study (e.g. comments from 1st year lab formal reports should be used to help improve your 2nd year lab formal reports). 2.) The marking criteria or rubric provided for this assignment. 3.) The Department Technical Writing Handbook for Students.
As a group member of team antrix I learned a lot of things while doing the engineering case design study on Anti satellite weapons. During report making I learned teamwork,time management and most important research skills. The best thing About of this topic (Anti satellite weapon) is I learned about space in Deep manner and found the different solutions by which we can save our space and other things which are in space. - Aabid Bashir (ab1154)
Are there any aspects of this work that you would specifically like the marker to comment/or advise on? For example: "I wasn't sure if my figure formatting looked professional and would appreciate feedback on this aspect"
Student to add text here…

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3.) The Department Technical Writing Handbook for Students.

I felt Engineering Design Case Study was a valuable course and allowed me to get a good grasp of System design. The course was well taught and organized. Initially I was not much aware about the Anti Satellite Weapons Test and Space Debris, but by working on this Topic I must say that the past several weeks have been extremely valuable learning to me.

I have learned many new things about Space Missions by working on this Case Study. I hold this as one of the most informative concepts of all the Aerospace subjects.

-AFTAB MANSURI (asm54)

Are there any aspects of this work that you would specifically like the marker to comment/or advise on? For example: "I wasn't sure if my figure formatting looked professional and would appreciate feedback on this aspect"

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Describe how you have used AT LEAST ONE of the following sources of information to improve this piece of work:

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As a professional engineer, I am always ready for new challenges. And it excites me to know new things and explore new domains. Coming from a mechanical engineering background, this is a new domain for me. And that is what pulled me towards this Case Study. This case study is not only technical but teaches life lessons, too. There will always be an ethical dilemma in your life. So, after studying this, my mindset has somewhat changed and now I can deal with it more consciously.

When I started to study on this topic, I was not very familiar with it. I researched, read articles, read books and slowly I got to know about it.

I have done report writing in my graduation years. But those were all technicals. This time I experienced a new thing. This report writing is not boring. When you do work on it. You are getting knowledge and new experiences.

Rubric is the most helpful thing. It gives direction on what we should focus on. By analysing the rubric I got to know which part we should work hard on. I improved the flow of the report according to that.

Overall, by entering into this new domain, I learned something, I improved something and got a chance to add more knowledge in me.

- Umang Narendrabhai Modi (unm2)

Are there any aspects of this work that you would specifically like the marker to comment/or advise on? For example: "I wasn't sure if my figure formatting looked professional and would appreciate feedback on this aspect"
Student to add text here…