Insights Toward an Ethical Assessment of CubeSat Technologies

(pre-print draft)

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Abstract:

The rise of new technology usually comes with new ethical questions. The technology behind cube satellites and small satellites is no exception. This chapter provides an overview of some of the main ethical issues involved in these specific technologies. We consider the relevant issues by distinguishing between anthropological, environmental, and social concerns. Most of these problems appear to be connected to different degrees, and together they show how so-called CubeSats can influence human life on Earth. For this reason, it is important to delineate a narrow and a broad interpretation of space ethics, the latter of which we take to be most appropriate for an assessment of this technology. The effects of these technologies on different stakeholders will also be considered through the outlining of an Ethical Matrix to identify the conflicts that will eventually appear throughout different scenarios of their use.

1. *Space ethics and nanosatellites*

The emergence of new technology usually comes with new ethical questions. The technology behind cube satellites and small satellites is no exception. This chapter provides an overview of some of the main ethical issues involved in the use of these so-called CubeSats. In highlighting the ethical issues that these technologies can raise, it is important to define two preliminary elements: the premises and the tasks of space ethics and, the morally relevant applications of these nanosatellites. From this perspective, the boundaries and the complexity of the ethical framework connected with CubeSats should appear—at least in a liminal way—clear.

Starting with the first of the two preliminary issues, space ethics, a sub-discipline of applied ethics, can be defined in either a narrow or a broad sense. In a narrow sense, space ethics is the investigation of all the specific ethical issues arising from human activities occurring beyond the terrestrial environment. If we take the Earth as a metaphorical center, space ethics should be considered, in this narrow sense, mainly outwardly oriented. Its main field of investigation is the various ethical challenges posed by space exploration: for instance, how we should approach, from an ethical standpoint, long-term space travel, space colonization, terraforming, extra-terrestrial life, and so on (Pompidou, 2000; Arnould, 2011). Born as a discipline with its pioneering works published in the ’70s and ’80s, this version of space ethics has been claimed to now be in its “early stage of consolidation” (Schwartz & Milligan, 2016), and it is set to become increasingly crucial following advancement in our capacity to explore deep space.

In a broader sense, however, space ethics, together with these outwardly oriented ethical issues, also includes the ethical investigation of the inwardly oriented dimension of space activities—that is, of their immediate and long-term earthly repercussions. While the main task of space ethics in the narrow sense is to adapt or even reinvent our moral compass to approach new scenarios—often radically different from those with which moral thinking has confronted itself over the centuries—space ethics in the broad sense adds a new task: the exploration of “old” earthly scenarios in light of the changes brought about by space technologies.

While nanosatellites play an important role in space exploration, the ethical issues they raise are mainly inwardly oriented—that is, they are most relevant for their consequences, both direct and indirect, on our planet and the people living on it. To refer to our previous characterization, an ethical assessment of nanosatellites requires a broader interpretation of space ethics than the one that is usually adopted. This conclusion should become evident if we take a look at the principal applications of nanosatellites—and, more specifically, of CubeSats—which can be classified into four categories (Pang, 2016; Villela, 2019):

a) *Educational purpose*: providing training for students.
b) *Research purpose*: testing new technologies, performing research in space, observing and imaging the Earth, etc.
c) *Governmental purpose*: managing disasters and human policy, using for surveillance and military, etc.
d) *Commercial purpose*: providing profitable services.

The expected future increase of nanosatellite use for interplanetary and deep-space missions (Freeman, 2020) will surely complicate this framework, introducing novel issues to be evaluated. In any case, at least for the moment, the central ethical issues of nanosatellites technology are found outside the boundaries of space ethics in the narrow sense and must be examined in light of their social, anthropological, and environmental effects on life on Earth.

Table 1: Overview of ethical issues for an assessment of CubeSat technology

Anthropological	- Analysis of artifact interaction - Addressing new needs and desires
Environmental	- Debris - Sustainability
Social	- Fair access to space technologies - Democratization of space research

Table 1 summarizes the main ethically relevant issues associated with CubeSat technologies. In this chapter we will follow this tripartition, dedicating a paragraph to each general issue. In the last section we will provide an overall look at the ethical issues related to this technology, highlighting both possible criticisms and positive aspects.

2. *Anthropological issues: Ethics and technology*

Ethical investigation of specific scientific and technological practices has seen major interest since the ’70s. One of the first cornerstones laid by the discipline was the principle that technological developments were to be carefully evaluated, given their potential unexpected negative effects (Jonas, 1984). Indeed, new technologies not only pose ethical questions regarding their specific usage but also raise greater anthropological issues, especially when the scope of their consequences (either positive or negative) reaches even future generations. Technological developments thus extend our moral responsibility far beyond the mere present along the dimension of time and, along the dimension of space, far beyond ourselves to other living creatures and the environment as a whole (Jonas, 1984).

Studies on the ethics of technologies delve into the interaction between human beings and technological artifacts, considering especially how technologies can shape human experience. Obvious examples are computers and smartphones, as these artifacts have, in a few decades, rewired countless aspects of our existence. One of the crucial questions that the ethicist of technologies tries to answer is whether a specific technology has a moral impact that can affect our deliberations.

A compelling answer is provided by ethical instrumentalism (Pitt, 2014). In this framework, technologies are mere tools, and what we need to consider from a moral standpoint is only the way we use them. We cannot ascribe a moral status to an artifact per se—*how* it is used is all that matters from an ethical standpoint. In this way, ethical instrumentalism goes hand in hand with the “value neutrality thesis”—that is, with the claim that “technological artifacts do not have, have embedded in them, or contain values” (Pitt, 2014, p. 90). This claim is supported by a pragmatic understanding of value, meaning that we cannot have the empirical experience of a value unless we witness (either directly or indirectly) someone who acts in a way that expresses a motivation to bring about a certain state of affairs. Values appear to be what motivates our agency: in these terms, as technologies are unable to bring about proper agency, it is impossible for them to embody or express values, aside from metaphorically.

This is not to say that technological artifacts cannot influence our choices. Indeed, ethical instrumentalism supports the claim that we can recognize in an artifact the values of its designer and that these values can exercise a certain prescriptive strength. This does not mean, however, that we ought to hold artifacts responsible for the state of affairs to which they contribute: rather, it is their designers who should be questioned (Fasoli, 2020). One of the greatest strengths of ethical instrumentalism is precisely that it does not disengage people from moral responsibilities by claiming, for instance, that part of the accountability for a given outcome is to be shared with the artifact (a weapon, for instance) they employed in bringing it about. This distinction might sound trivial, but it is actually relevant in many cases, such as in accidents caused by malfunction. Ethical instrumentalism's claim here is that it is not the technology or the malfunction per se that is responsible for the bad state of affairs created; rather, it is always *someone*'s responsibility.

Still, we cannot fail to acknowledge that technological artifacts can have an influence on our behavior, as they do exert prescriptive strength. This position is generally defended by mediation theory. This theory holds that technological artifacts, by mediating our interaction with the world (i.e. imaging and screening technologies) in various ways, play a relevant role in the way we understand it. Hence, designing technology means designing relations between human beings and the world, which ultimately shapes how human beings are (Verbeek, 2016). For this reason, technological artifacts cannot be understood in the purely instrumental way defended by ethical instrumentalism. Rather, we need to take account of their prescriptive strength. Every technological revolution—or at least those of a magnitude analogous to what the advent of nanosatellite constellations purports to be—causes an anthropological shift: a change in people's way of thinking and living, on both an individual and a social level. This transformation happens primarily because new technologies fulfill pre-existing needs and, at the same time, create new ones. The types of new needs created, and the ways in which it will be possible to satisfy them, will, more than anything else, provide the key to understanding the ethical challenges raised by the new technology in question.

To evaluate these challenges in the wake of CubeSat technology, it will help to follow the three dimensions used in mediation theory to evaluate the moral reach of a given technology (Verbeek, 2016). First of all, it is necessary to reflect on the types of relations this kind of technology brings about (Idhe, 1990). The relation between human beings and CubeSats is, on the one hand, one of embodiment, as people use them to interact with the world through, for example, communication services. On the other hand, it is also hermeneutic, as people look at the world through them, as with imaging devices.

Next, when investigating a technology, we should reflect on its contact points—that is, on the specific processes through which interactions with it occur (Dorrestijn, 2014). In some cases, the interaction is direct, as, for instance, when technology presents itself as a physical impediment (i.e. speed bumps) or as an aid of some kind (i.e. lifts). In other cases, the interaction is indirect and contextual, as when technology shapes our perception of an environment (i.e. surveillance cameras). The interaction may even be "before the eye", cognitive rather than physical or perceptual, facilitating the obtaining of information that would not be possible to acquire otherwise. In cognitive relationships, it is important to underline that the information the technology presents us and the processes by which it happens are not trivial matters. The selection and manner of sharing information shapes our beliefs and accordingly has some degree of prescriptive influence in directing our actions, even if not necessarily in a *deterministic* way.

Finally, we should consider the type of influence that the given technology exercises on its user's experience. This aspect can be evaluated along two scales that classify the *force* (from weak to strong) of the influence and its *visibility* (from hidden to apparent) (Tromp et al., 2011). A car that will not start until the passengers have fastened their seatbelts is an example of an artifact that has a strong and apparent influence, also called *coercive*. A township that arranges a nice public park in order to encourage social exchanges among citizens mobilizes artifacts designed to have a weak and hidden influence—that is, *seductive*. It is important to highlight that CubeSats are not specifically designed to influence our behavior in some way. Still, as with all artifacts, they do open up new services and technologies that broaden the possibilities of our agency; for instance, some places are much harder to reach without a GPS. The best way to describe technologies related to CubeSats is to expect them to have an apparent and weak—*persuasive*—influence on our behavior. This influence is especially evident with the increase of their commercial use. It is *apparent* because they explicitly contribute to certain areas of employment, such as communications service industries, which holds even if their application might be obscure to regular technology users. Also, they appear to exert a *weak* influence, since they are not expected to coerce any behavior; rather, they might suggest and spread the usage of certain services due to the appeal of more affordable and accessible attainment.

All these considerations—about the types of relation, the processes of interaction, and the influence of these technological artifacts—make it easier for us to conclude that designing technology ultimately means designing relations between human beings and the world. It is worth asking how the widespread introduction of CubeSats will shape these aspects of human life. From an anthropological point of view, this issue is not secondary: technology can define what human beings are able to know, what we believe, and, in the end, who we are. The design of new services based on CubeSats technology cannot have a purely instrumental approach, as "designing technology is designing human beings" (Verbeek, 2016, p. 28).

3. *Environmental issues: Sustainability*

Space debris is often cited among the ethically relevant issues related to astronautics and space exploration (Schwartz & Milligan, 2016). Indeed, it poses a real threat to space operations in near-Earth space. The presence of debris endangers the lives of astronauts and the functioning of operative satellites. It necessitates both constant surveillance, which drains resources that could be spent elsewhere, and for evasive maneuvers, which deplete the energy sources of spacecrafts. Collisions create more debris, triggering a cascade effect.

Space debris is also constantly falling onto the Earth's surface—one object per day for the past fifty years, according to NASA, with an event once per week related to an object with a mass of at least 2,000 kilograms (Hall, 2014). As most debris disintegrates in the process of reentry, plunges into the oceans, or scatters over sparsely populated areas of the planet, reported incidents involving people or property are few (Bergamini et al., 2018). However, it is not clear what the long-term environmental impact of this constant bombing could be on Earth, as some of this debris is toxic (Ferrando, 2016).

From a value standpoint, debris pollution is a particular type of environmental issue. Environmental value, as recapped in **Table 2**, can be categorized along two axes (Biasetti & de Mori, 2016).

Table 2: Forms of environmental value

	Non-anthropocentric	Anthropocentric
Non-instrumental	i.e. biocentric value, ecocentric value, etc.	i.e. aesthetic value, epistemic value, existential value, etc.
Instrumental	i.e. ecological value	i.e. economic value, service value, etc.

[CAPTION] Environmental value, as it can be categorized according to the instrumental/non-instrumental and anthropocentric/non-anthropocentric axes. Having instrumental value means having value as *a means towards an end*. Having non-instrumental value means having value *as an end*. Having anthropocentric value means having value *for human beings*. Having non-anthropocentric value means having value *independent of human beings*.

The long-term environmental impact of reentering debris can affect both the instrumental and the non-instrumental dimensions of Earth's value in the anthropocentric and non-anthropocentric instances of each. The collision risk involves the instrumental and anthropocentric dimension of near-Earth space. In this regard, we may ask whether we can provide reasons for valuing near-Earth space from a non-instrumental standpoint. Using a non-anthropocentric view, it is rather doubtful that we could assign ecocentric or biocentric value to natural places incapable of sustaining life. No known organisms, aside from tardigrades (Jönsson et al., 2008), are able to survive the extreme conditions of low Earth orbit. In this sense, near-Earth space cannot be valued from a non-anthropocentric standpoint. Still, it may perhaps be considered valuable for non-instrumental yet anthropocentric reasons. Beauty, knowledge, and reverence are three important non-instrumental yet anthropocentric values. At least one of these—knowledge—is very likely applicable to near-Earth space, providing a further reason to avoid littering, especially as it could seriously compromise the success of scientific endeavors.

CubeSat missions, however, play a minor role in debris pollution. As we write, there are 222 non-operational nanosatellites in orbit, less than the 368 satellites that have already reentered (see **Figure 1**), representing 1.08% of the 34000 items of debris larger than 10 cm recorded by the ESA. The altitude of the orbit chosen for the mission is the main predictor of how long a CubeSat will remain in space after becoming inactive. High-altitude orbits can increase the lifespan of CubeSats beyond the 25-year maximum required by space debris regulations. Early CubeSats missions showed a low compliance with this maximum (Oltrogge & Leveque, 2011), which was mainly the result of limited launch opportunities (Swartwout, 2016). With better choices and dedicated launches during these last years, compliance with this requirement has increased (Pang et al., 2016; Braun, 2020).

The status of CubeSats as minor agents of debris pollution could change due to the expected surge in missions and the advent of constellations – large groups of similar satellites working together as a system (Bastida et al., 2016). While some constellations are based on the CubeSat paradigm (i.e. Planet's PlaneScope), most are not (i.e. SpaceX's Starlink, OneWeb and Amazon's Project Kuiper), although they do fall into the SmallSat category. Constellations are criticized for the light and radio pollution they create, impairing astronomical research (IAU, 2019). Moreover, a growth in the demand for launches could lead to a situation where high orbits and the accompanying debris pollution are the only option for many missions. Constellations are expected to quadruple the number of existing operational satellites in the next few years (Robert et al., 2020). The growth in the number of small satellites in orbit would further increase the importance of developing efficient technologies and protocols for post-mission disposal. These strategies may still not be enough. Many constellation missions target orbits 1000 kilometers high (Braun, 2020), and failure to dispose of even a few satellites—which, given their proliferation, is statistically possible even with a high success rate for post-mission disposal—would create debris with a very long-life expectancy. It is thus no coincidence that the risk of collision due to inactive CubeSats, while low at present (Swartwout, 2016), is nevertheless expected to grow in the near future (Matney et al., 2017).

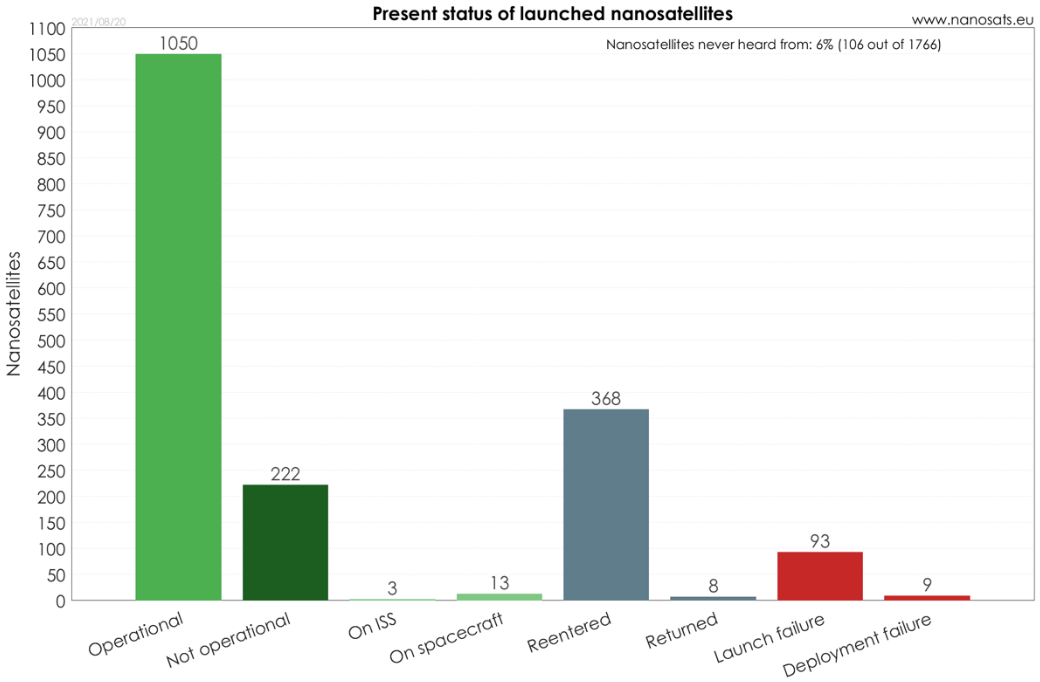


Figure 1

Besides compliance with the 25-year maximum lifetime and the passivation of the spacecraft in order to prevent explosions, several other strategies have been proposed to mitigate the impact of CubeSat missions on space debris. The addition of de-orbit devices, for instance, is often suggested (Lewis et al., 2014). Being in many cases low-cost endeavors, CubeSat missions often cannot afford these kinds of devices. At the same time, however, they may provide unique opportunities for testing new solutions and collecting data on existing devices.

CubeSats can thus become part of the solution instead of limiting themselves to being a relatively small part of the problem. Taking a proactive stance on debris removal (Hakima et al., 2018) has been suggested as a necessary step in order to assure the long-term vitality of the CubeSat community

(Oltrogge & Leveque, 2011). In a similar way, CubeSats could play a key environmental role on Earth by assisting in disaster management (Santilli et al., 2018), wildlife monitoring (Woellert et al., 2011), agriculture and natural resource efficiency (Madry, 2020), pollution control (Pelton, 2020), and other important tasks for the safety of people and the conservation of biodiversity.

If some such initiatives become effective, they will certainly create a positive context around this specific technology and will help it reach the objective of sustainability for single missions. The nature of the issue, however, is such that only collective action can definitively resolve it. Like many other analogous scenarios of environmental exploitation, space debris pollution follows the classic pattern of the tragedy of the commons, with the ultimate saddle point here being the Kessler syndrome. For this reason, international regulation is perhaps the only chance to reach a definitive solution, as unilateral action is usually limited in its reach and effects (Johnson, 2003). While the sustainability of each mission should remain a priority, strong pressure should be exerted on stakeholders to reach a collective agreement for the sustainable use of near-Earth space.

4. Social issues: Accessibility

The advent of SmallSat technology has often been labeled a “revolution”, and it certainly constitutes a paradigm shift in space technology (Sweeting, 2018; Pelton & Madry, 2020). The defining features of this revolution do not lie solely in the mere size of the devices—small satellites are certainly nothing new. The paradigm shift resides rather in the different organization of satellite design and production. Modern small satellites are built from commercial, off-the-shelves products, triggering a virtuous circuit that improves the price and quality of these components through the increase in the volume of their use (Cheong, 2020). The relatively limited price to pay for mission failure makes possible rapid and repeated cycles that allow the incremental development of technologies—something usually precluded in other areas of space research (Welle, 2016; Nayak, 2017). Design and construction are carried out by small, agile, and motivated teams with a structure similar those working with information technologies (Sweetings, 2018). Moreover, compared to other small satellites, CubeSats offer the further advantage of simplifying the interface between cargo and carrier, creating a universal standard similar to intermodal containers in freight transport (Welle, 2016). These characteristics are all new, and they form the core of the paradigm shift produced by CubeSats.

There are two ethically interesting issues with this “revolution”. The first concerns its possible future developments, while the second involves instead its effects on the accessibility of this type of technology, especially globally.

The first issue requires notice of the growth of commercial missions compared to those carried out by universities. From this point of view, the technology behind CubeSats and, more generally, SmallSats seems to be ready for a further paradigm leap (see **Table 3**)—from the present landscape, dominated by small teams with well-defined goals, to the large-scale production required by constellation projects that have more ambitious objectives and need to rely on the industrial production economy.

This paradigm leap seems to be inevitable, given the growth forecasts for the next decade of the CubeSat market. The increase in the standardization of production, the steady incremental development through ever-faster cycles, and the drop in prices for commercial, off-the-shelves components thanks to the increase in demand will probably lead to this new scenario faster than expected. The degree of the shift’s ethical impact will depend on how the various “saturation” issues are dealt with: among these, beyond the aforementioned issue of debris, can be included the congestion of orbits, the overcrowding of radio frequencies, and the need to invest even more resources in situational awareness (Robert et al., 2020).

Table 3: Paradigms in satellites production

	Pre-CubeSats	**Early advent of CubeSats**	**Constellations**
Model of organization	Military–aeronautical agency	IT technology	Industrial mass production

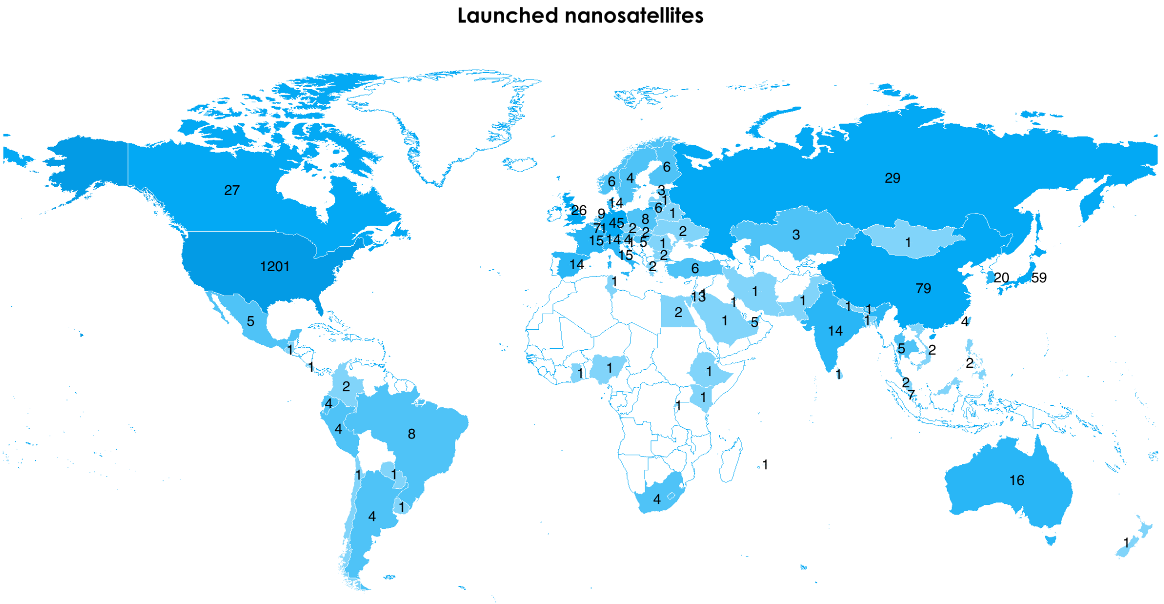
Costs of production	High costs	Low costs	Scale economy
Technological development	Non-incremental development	Mixed	Incremental development

One aspect of the original CubeSat "revolution" is the adoption of an open philosophy to design that contrasts the classic closed approach typical of the military–aerospatial agency model of organization (Scholz & Juang, 2015). CubeSats would favor a more interconnected approach to the space enterprise, one diametrically opposed to the competitive paradigm exemplified at its height by the Cold War's space race. It is not clear, however, if this aspect is destined to be dampened, at least in part, by the transition from mainly the educational and scientific use of this technology to that in which commercial stakeholders are more and more preponderant.

This latter point naturally raises the issue of the global accessibility of this technology. One of the recurring claims about CubeSats is that they have lowered the entry level for space programs (Cheong, 2020). Indeed, CubeSat technology has allowed many countries to enter space research for the first time and, in this way, to diversify and enhance their educational and research capabilities (Wood & Weigel, 2014). In addition to these opportunities, CubeSats could also offer many developing countries the possibility of obtaining the services usually offered by larger satellites at a low cost (Woellert et al., 2011).

The distribution of missions by country, reproduced in **Figure 2**, shows that this "democratization" of space produced by CubeSats, while existent, is perhaps overstated. The overwhelming majority of missions are, in fact, concentrated in the United States, followed, at some distance, by countries with already sophisticated space programs. This gap seems inevitable, at least in the beginning, and it is far from clear if it will be reduced in the future, especially given the increasing dominance of commercial missions.

Figure 2

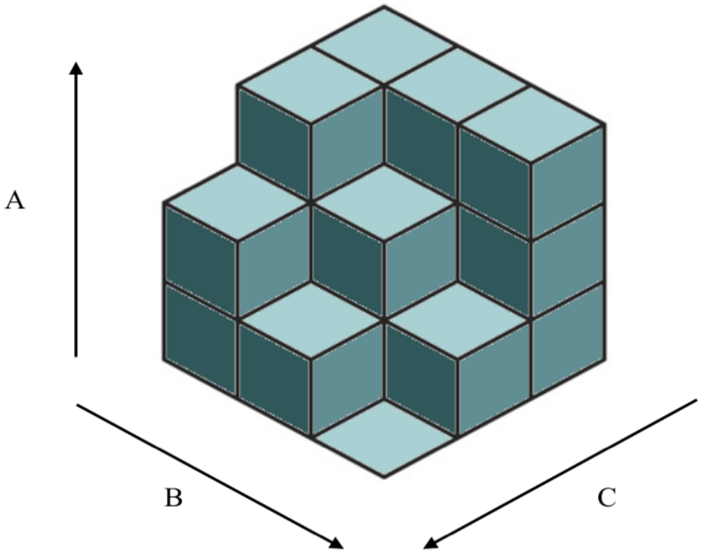


Launch costs are the main expense item in the budget of a CubeSat mission. The increase in commercial missions could have the effect of causing them to decrease thanks to the development and use of dedicated carriers. Yet, it could also have the opposite effect, saturating the available slots in carriers and thus raising the economic requirements of future missions. In this way, the technological lag between countries could even increase rather than decrease.

5. *The ethical matrix: Insights for an assessment of CubeSats*

Any specific assessment of a CubeSat mission entails focusing on two interrelated aspects of it: its importance in terms of the possible value dimensions involved—educational, scientific, commercial, technological, etc.—and its chances of success. By quantifying all potential costs of the mission, including the eventual social costs, like debris production, a third axis becomes available upon which to build a simple, three-dimensional cost–benefit assessment model (refer to **Figure 3**) like the one provided by the Bateson cube for research involving animal experimentation (Bateson 1986, 2005).

Figure 3



[CAPTION] The cube is a decision tool that summarizes and displays the possible combinations between scores attributed along three dimensions—in this case; a) the costs of the missions, including social costs, like those derived from the potential production of debris; b) the chances of success for the mission; c) the potential value of the mission, in terms of scientific, educational, commercial (etc.) benefits. High scores on the axes represent low costs, high chances, or substantial values, while low scores portray the opposite. Acceptable scenarios are represented by the clear space in the cube, while unacceptable scenarios are represented by solid spaces. Note that on one of the axes (in this case the value of the mission axis), at least a medium score is necessary (but not sufficient) in order for the result to be acceptable.

In order to be effective, such a model would require a detailed analysis of the parameters used for assigning scores in the three delineated dimensions, which is beyond our scope here. Nevertheless, CubeSat missions have peculiar characteristics that must be considered in establishing criteria for scoring. The measure provided by the chance of success, for example, must be evaluated according to the specific context of a mission. In some cases, failure means the interruption of funding and consequently the wasting of the resources invested. In others, it may be a risk widely anticipated and accepted as part of a strategy aimed at ensuring the incremental development of a given technology through the iteration of rapid cycles: in this case, it is the chance of the success of the overall project that should be evaluated, not the chances of a particular launch.

Analyzing the value of a mission and its chance of success is crucial, as futility is one of the charges most often levelled against CubeSat missions (Almine, 2009). Many of the first CubeSats were indeed “BeepSats” that served no other function than “beeping” telemetry (Swartwout, 2013). Moreover, the failure rate of missions, while declining over the years (Villela, 2019), has been traditionally high, which has raised some skepticism about the efficacy of CubeSats in carrying out scientific missions of a certain relevance (Cheong, 2020). CubeSats’ futility is still one of the most common complaints faced by this technology, especially considering the modesty of the scientific or commercial objectives associated with many missions. However, this argument can be easily countered. Evidence that CubeSats are not academic “toys” comes from the constant growth of their use in commercial and research missions (Villela, 2019). Moreover, their overall value needs to be considered by looking at the larger picture of their use. Even with a high failure rate, CubeSats can still play an important role in research when fast and low-cost reiteration cycles are required (Poghosian & Golkar, 2017). Indeed, as noted before, the possibility of implementing fast cycles and the relatively low price of failures are what allow the incremental development of this technology (Welle, 2016), which also positively affects the education applications of CubeSats. As they are quick and cheap to build, simpler projects can be employed for hands-on instruction of spacecraft system engineering. Even the seemingly useless BeepSats may thus have great potential in terms of capacity building.

However, a responsible and sustainable approach should still pass the test of a careful and transparent cost–benefit analysis that also takes into account the potential risks. This kind of analysis reaches a very high level of sophistication in standard space missions. However, the methodologies and tests employed in these cases are not practicable for CubeSat missions, due to time and resource limitations (Cheong, 2020). The specific environment of CubeSat missions—the use of commercial, off-the-shelves products, the involvement of students, etc.—is such that they would require the development of a specifically dedicated tool for assessment (e.g. Zea et al., 2016).

Awareness of the possible ethical issues—and positive outcomes—associated with this technology is necessary to carry out a detailed and complete analysis. **Table 4** uses the Ethical Matrix tool (Mepham, 1996) to provide a preliminary ethical assessment of CubeSats. In the Ethical Matrix we present here, the impact of the technology is assessed according to the value demands that could be advanced by potential stakeholders, categorized by three general ethical principles: well-being, autonomy, and fairness.

Table 4: Ethical matrix

	Well-being	**Autonomy**	**Fairness**
People	Sustainable development *Pros*: several possible uses for sustainable agriculture, fishing, forestry, and other forms of resource management. Economic profitability of the technology may have positive benefits for all society. Few if any social costs. Interactions *Pros*: uses in communication and imaging services, fostering possibilities for human interactions. Health *Pros*: uses in disaster management and pollution control. Research on weather and alternative energies.	Personal autonomy *Pros*: various opportunities for business, education, research, etc. fields. *Cons*: new technologies may elicit new unwanted needs, which are nevertheless inescapable for social reasons. Further contribution to “satellite voyeurism”.	Fair treatment *Pros*: low-cost technologies may partly level the field between developed and developing areas of the world, lowering the cost of services even where there are few or no traditional infrastructures. *Cons*: new technologies may elicit new needs, and this may create new inequalities between people depending on their accessibility.
Environment	Biodiversity conservation *Pros*: possible uses for ecological purposes, including uses specifically targeting biodiversity conservation. *Cons*: space debris may cause pollution on Earth (CubeSats, however, have a scarce chance to survive reentry).	–	–
Governments	Safety *Pros*: uses in disaster management and pollution control. Research on weather and alternative energies. Possible uses in surveillance. *Cons*: possible uses in intelligence gathering may require military expenditure and arms race.	Rule of law *Pros:* most aspects of the technology may already be subsumed under existing laws, regulations, and best practices for normal satellites. *Cons*: this set of rules is not as definite and internationally shared as is probably required.	Accessibility to space *Pros*: low entry level makes possible accessibility to space even for countries with no previous space program. *Cons*: excessive proliferation could in time saturate orbits and limit accessibility for some countries.
Businesses	Economic profitability *Pros*: largely positive market	Freedom of business *Pros*: technology readily	Accessibility to business *Pros*: relatively low entry level.

	forecasts. Possibility of driving other market sectors (commercial off-the-shelves components market, for instance)	exploitable for several commercial uses.	Technology exploitable by startup and small-scale innovative business. *Cons*: as for most markets, it is probably destined over time to have increasingly demanding entry levels.
Universities and research institutions	Providing cost-effective education and training *Pros*: technology devised as an educational standard. Making quality research *Pros*: technology capable of having several important research uses. *Cons*: excessive proliferation could in time have a negative impact on astronomical observation from Earth.	Academic and research freedom *Pros*: possibility to participate in space research.	Accessibility of the technology *Pros*: low costs. *Cons*: excessive proliferation could in time saturate orbits and limit accessibility.
Students	Access to education and training *Pros*: possibility of hands-on experience in space system engineering.	Curriculum building *Pros*: possibility of participating in a space mission.	Accessibility of the technology *Pros*: global capacity building potential of the technology.

[CAPTION TO TABLE 4]

The ethical matrix is a tool made of rows and columns listing all the value demands linked to the technology assessed. In the first column, the ethical matrix lists the potential stakeholders involved. In the first row, it lists the three general ethical principles commonly recognized in pluralistic societies. Each value demand is obtained by applying the general ethical principles to the standpoint of the stakeholders relative to the scenario analyzed. Value demands are not absolute: in the case of a conflict, a trade-off should be formulated.

The Ethical Matrix lists several general value-demands that can be affected by CubeSats technology (i.e. sustainable development, academic and research freedom, accessibility to space, etc.). The value demands are then used as benchmarks to assess the impact of the technology by evaluating the pros and cons involved. Starting from this analysis, it should be possible to proceed to a further step—that is, the categorization of cons. Some may be raised by provisional or otherwise surmountable conditions; others may be structural and thus difficult or even impossible to avoid. Knowing the exact nature of the con will make it easier to develop possible strategies to mitigate its effect and hence to assess its weight in comparison to the pros.

6. Conclusions

Many cons of the value demands are typical of most satellite technologies (satellite voyeurism, debris pollution, arms race triggered by the possibility of using satellites for intelligence gathering), while others are familiar instead from discussions of new information technologies (creation of new needs inescapable for social reasons, possibility that these new needs will create disparities). Taken individually, they do not constitute something new; nevertheless, these cons cannot be considered less problematic. Most of the content of the Ethical Matrix can be extended to other SmallSats. Constellations, however, whether based on the CubeSat paradigm or not, will be great game changers that will alter the existing equilibrium. Finally, given the moral insights provided here, we conclude that an overall positive assessment of future developments of this technology will largely depend on its ability to continue to meet the expectations of the various pros listed without exacerbating the effects of cons.

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