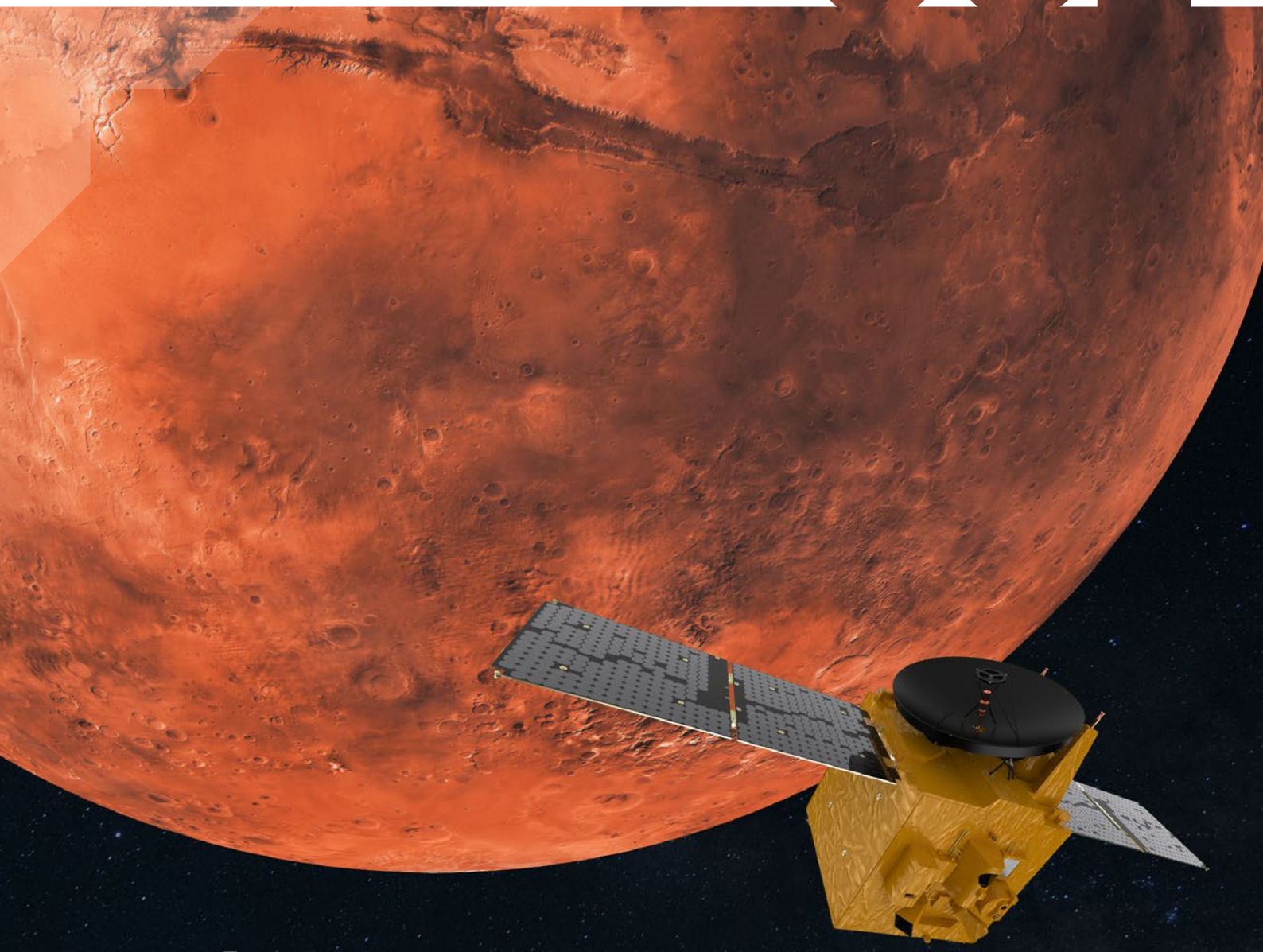
DEPARTMENT OF SCIENCE, TECHNOLOGY,
ENGINEERING AND PUBLIC POLICY

UCL



Emirates Mars Mission

A mission to a transformative future

A transformative value analysis report for the Mohammed Bin Rashid Space Centre

About UCL

UCL is one of the world's leading multi-disciplinary universities, with students from over 150 countries and more than 13,000 staff.

Founded in 1826, UCL was the first university in England to welcome students of any religion and to welcome women on equal terms with men.

The UCL Department of Science, Technology, Engineering and Public Policy (STEaPP) mobilises science, technology, engineering and policy expertise to help change the world for the better.

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Staff of the UAE Office of Advanced Sciences

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UoC Boulder & ASU interviewees

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Methodology

The content of this report is drawn from multiple sources and we have used a combination of corresponding data collection and analysis techniques. These included a review of international academic and grey literature on the value of space missions; interviews with international experts; and meetings and workshops with the staff of the MBRSC. The research team also benefited from parallel engagement with the UAE Office of Advanced Sciences. The team has also drawn on findings from previous research. Further details, including the accompanying technical reports, can be found on the UCL Department for Science, Technology, Engineering and Public Policy website (www.ucl.ac.uk/steapp).

Executive summary

Highlights

- Distinctive for catalysing national development with a space mission
- Remarkable on-time, on-budget development
- Innovative capture of transformative value
- Success in building future capacity
- Catalyst for long-term regional and global leadership

In July 2020 the United Arab Emirates will launch a satellite to Mars to study its atmosphere and climate. There is much that we do not know about our neighbour planet. What is its weather like across the seasons? How does its climate vary across its geography? And why is Mars losing its atmosphere?

Using an innovative orbit trajectory and combination of three scientific instruments, the Emirates Mission to Mars (EMM) will provide scientists around the world with data to better answer these questions and understand the inner workings of planetary atmospheres, including our own.

Distinctive & Ambitious

The mission is notable for more than the science it supports. Its true distinctiveness is more easily appreciated when the motivations that propel it are considered.

Outer space missions typically depart with a question for science before they ask how their value can extend to the society behind it. The EMM inverted this traditional logic. Instead, its conception arose from a quest to fundamentally redirect a nation's trajectory. Through its design and execution, the EMM pursues a UAE future in which its economy diversifies from traditional activity, including oil and finance, and inspires a generation towards scientific and entrepreneurial careers – and away from other, less societally beneficial pathways. This is a mission for national development before it is a mission of science.

Equally remarkable is the mission's journey to its launch date. Despite no previous domestic space exploration experience, an absence of planetary science capacity, lack of the requisite infrastructure, and a deadline within approximately half the time used by other comparable missions, a core mission delivery team constituted 100% of local, Emirati staff with an average age of under 35, are on time and within budget for launch. Where a few years ago the UAE had no presence in space, it now joins, as the first Middle Eastern mission, the small cadre of nations who have sought to reach Mars.

Regional leadership

All of this is happening at a time when the MENA region is in a state of flux, with a shift in power within the region and changing influence of external stakeholders. For the UAE, which finds itself at a crossroads, the EMM therefore offers a pathway to the country playing an increasingly influential role within the wider global knowledge economy.

Transformative value

During spring of 2019 a group of UCL researchers met with the EMM team to discuss the ways in which science can support a nation's development. This study followed from an agreement that an independent review could elucidate a set of shared interest questions: can a single science mission catalyse a national transformation?

What lessons can be learnt from the UAE's approach to mission delivery? What is the impact so far? And what evidence, if any, is there of transformative value generated?

A practical challenge was immediately faced. Usually when questions are asked to capture the value of outer space activity, only a portion of the picture is considered. Typical mission value measurement tools support only partial capture of the story. We therefore drew on the lessons and experiences of others and developed a new method to capture the impact of science missions: the Transformative Value Canvas.

Strategic & Impactful

Despite the early stage of the mission, we found early evidence that the EMM is already impacting multiple development processes. In the domain of science, the mission has nurtured new domestic expertise and positively changed its reputation within the international space community. Within the national space economy, the mission has laid a foundation for the UAE to be engaged as a trusted collaborator on future international programmes. This foundation comprises both the construction of tangible facilities, as well as development of equally significant, yet intangible, complex programme management know-how and skills. At the national level, the mission's outreach and engagement programmes are noticeably changing perceptions about the attractiveness of science careers and have prompted the creation of new university degrees. Finally, the evidence suggests that at the international scale, the mission has opened a diplomacy track in its reputation for its science and innovation capacities that can support the UAE's leadership and efforts in enhancing regional and global prosperity and well-being.

Of significance is the purposive approach employed in the EMM's design and delivery. A nation with a relatively short space track record typically chooses one of two options when embarking on an exploration mission: 1) to rely primarily on the space capability of other global actors and commission off-the-shelf services; or 2) to build up national capability iteratively via Earth and lunar orbit programmes. The EMM chose to do neither, and instead conceived its own original and innovative approach. From its outset it opted to ground the mission as a national effort, and accelerate through the learning stages by selecting to work with external global centres of expertise with an openness to joint capacity development. These partnerships have been crucial to unlocking the total value of the EMM.

Success & Future value

The mission's success is framed by a national vision for transformation. Its success is therefore not defined by whether the launch or scientific fieldwork are completed or not. Instead, success depends on making a significant contribution to support a transition to a broader based economy. These interrelated ideas about success and value are likely to make frequent appearances as the mission's progress is examined over the coming months and years. Mars missions are notorious for their high failure rates (~30% since early 2000s). Their technical complexities are orders of magnitude greater than those required for Earth orbiting. The UAE has thereby metaphorically leapt from the springboard of moderate satellite activity and somersaulted straight into the deep space end.

A final note is that these are early days to collect evidence of mission impact and value. The signals are there, however, to suggest that should the domestic capacities in science, space and know-how developed by the mission so far be provided with further opportunity for application and use, the EMM's overall societal value could be truly transformative.

60,000+
Young people and teachers engaged in Emirati space visions

New international philosophy for space mission delivery

On time ✓ On budget ✓

6 vs **10** Years

15+
International REU collaborations

New Standards

200+
New technical designs

34% Female team

Regional and global influence

Bilaterals with international agencies

1st UAE science diplomacy initiative

100%
Emirati core team

1+
Terabyte of new Mars data

5 New science undergraduate programmes

1 New postgraduate science programmes

2 science & technology start ups

Science Apprenticeship Programme

66+
parts domestically manufactured

100+
Peer review meetings

51
Publications

Contents

Part 1: The value of Space Missions

A UAE vision towards Mars

> Failure within the mission itself is an option. Failure to progress as a nation is not.

Omran Sharaf
Director of Emirates Mars Mission
Mohammed Bin Rashid Space Centre

Mission to Mars

In 2014 the UAE's President His Highness Sheikh Khalifa Bin Zayed Al Nahyan and the UAE's Vice President and Prime Minister His Highness Sheikh Mohammed Bin Rashid Al Maktoum announced a strategic national Emirates Mars Mission (EMM). The first such mission planned by a MENA region country, the intention is for its 'Hope' satellite to enter Martian orbit in 2021, exactly coinciding with the fifty-year anniversary of the founding of the UAE. Hope ('Al Amal') will then study the Martian atmosphere, gathering data to generate the first truly holistic model of the planet's weather system. The analysis and insights generated will help us better understand the atmospheric composition and ongoing climate change of our neighbour planet.

A national project

The EMM is more than a space science mission or celebration of the UAE's first fifty years. Beyond the science objectives, the mission is a national project that seeks to develop some of the capacities needed to better engage with the economic, social and geopolitical forces of the 21st century. It aims to inspire a young generation into pursuing of unfamiliar and innovative career pathways, and thereby support a diversification of its economy into a post-oil era. Mission success is therefore at least as much, if not significantly more, about nurturing capacities, than it is about the eventual scientific outputs it could produce.

The wider context

Over the past fifty years the development of the Middle East region has been dominated by economies based on hydrocarbons and the unipolar influence of the United States (US). However, this is rapidly changing, in part because states within the region are diversifying their economies but also because the US is seeking to disengage from an all-embracing regional role and only engage on selective issues.

It is commonly observed that this is happening at a time of not only rising regional tension and increasing incidents of conflict, often through the use of proxies, but at a time of the emergence or re-emergence of nations seeking to exploit the void created by recent US foreign policy. The important actors engaging in the region today include Russia, China and, increasingly, Turkey. In the case of Russia and Turkey involvement is principally in a security context. In the case of China, it is seeking to use its economic power to develop a strategic vison, centred on the Belt and Road initiative; one that competes with the US and is not always to the benefit of third nations. At the same time, there has been a global shift in many countries towards trying to create more knowledge-based economies, accompanied by greater policy focus on science and innovation and greater expenditure in these areas. However, to date and for a variety of reasons, many countries within the Middle East have not engaged in this transformation. They are, therefore, not enjoying current and potential benefits.

The UAE finds itself at a crossroad. Growing in stature in the region, it can focus on continuing to provide leadership and working to address the issues that it perceives as driving instability, something that it has found itself increasingly involved in this decade. Alternatively, it can do this but also work to play an increasingly important role in economic and political activity based on science and innovation as it seeks to tackle the challenges of the 21st century, including those identified in the Sustainable Development Goals.

Such an evolution has potential to further enhance the UAE's global standing. Yet, to be an effective participant in such an environment, the UAE will need to be able to demonstrate leadership in science, education, technology and finance. Some of the necessary competencies already exist for these, especially in the areas of finance and financial services, but it is also acknowledged that further development is required. This is reflected in the UAE Centennial 2071 plan and the approach taken by the EMM.

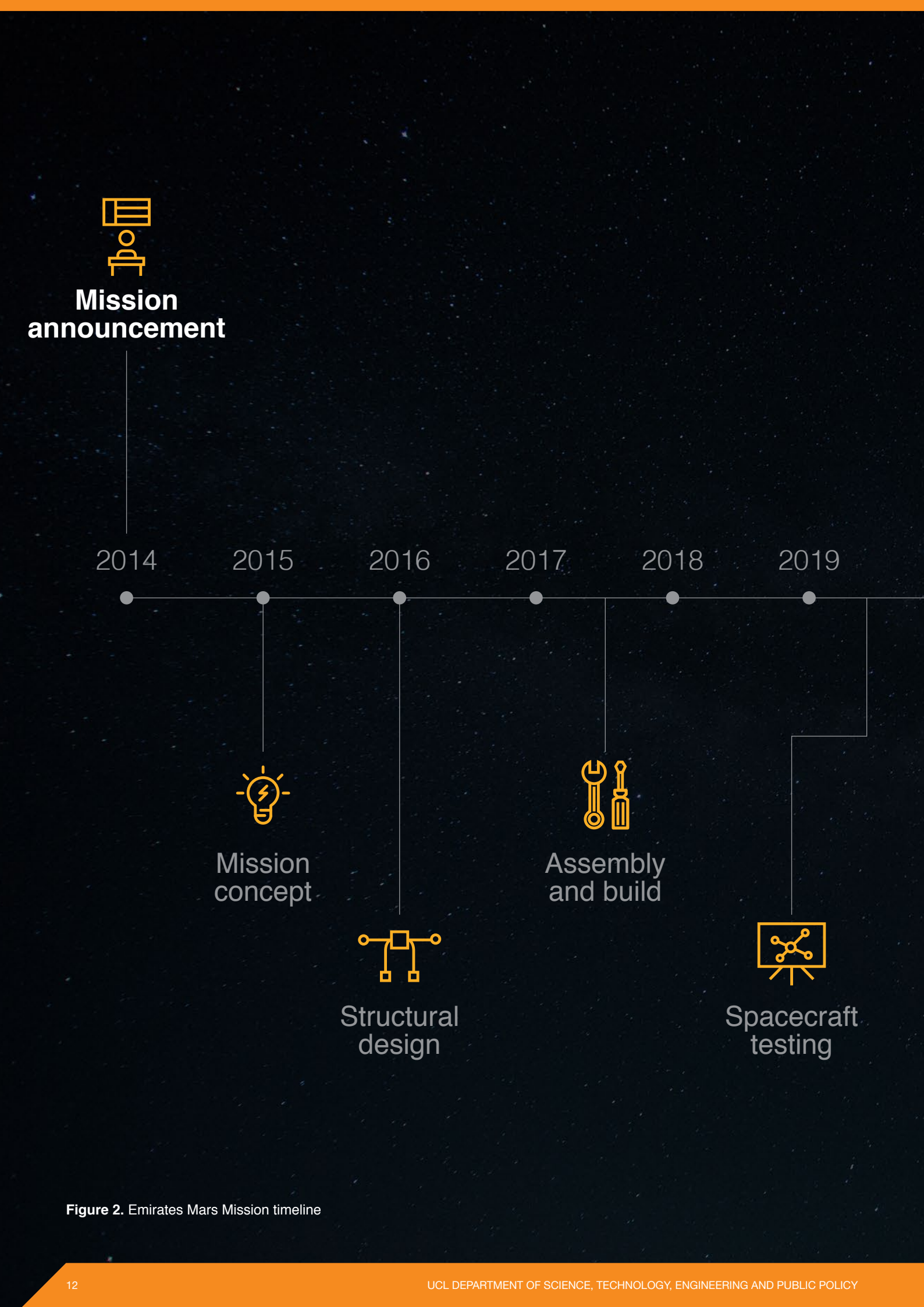
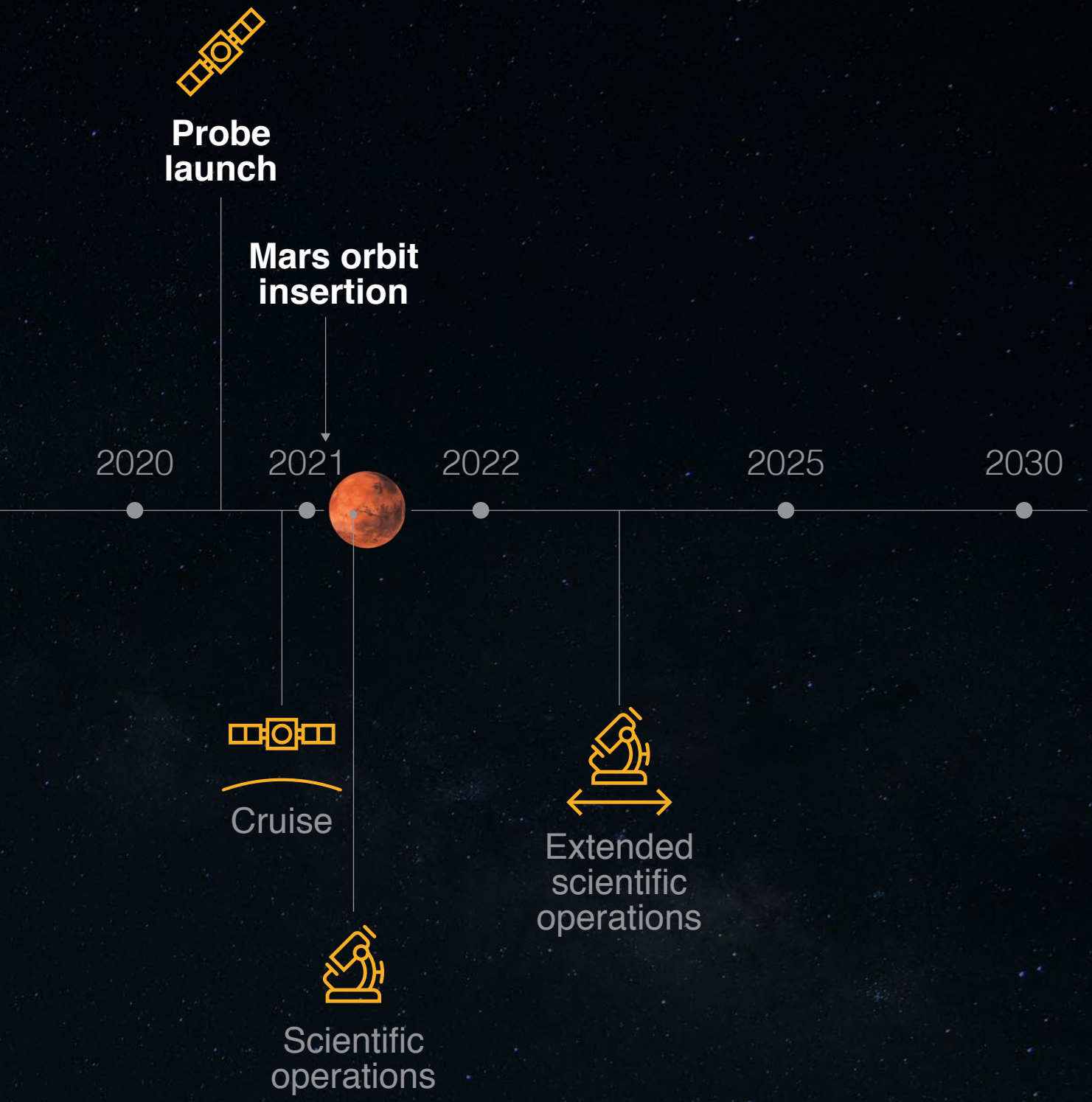


Figure 2. Emirates Mars Mission timeline


Probe launch
Mars orbit insertion
2020
2021
2022
2025
2030
Cruise
Extended scientific operations
Scientific operations

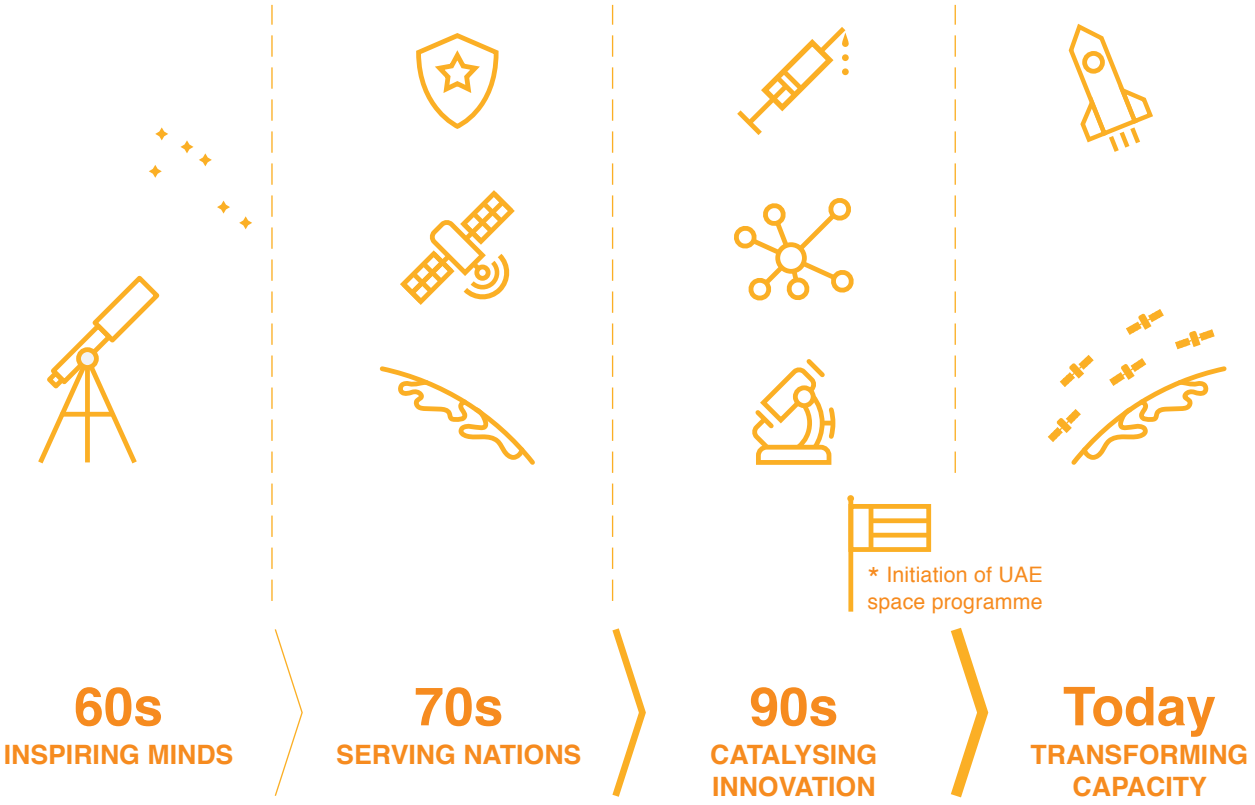
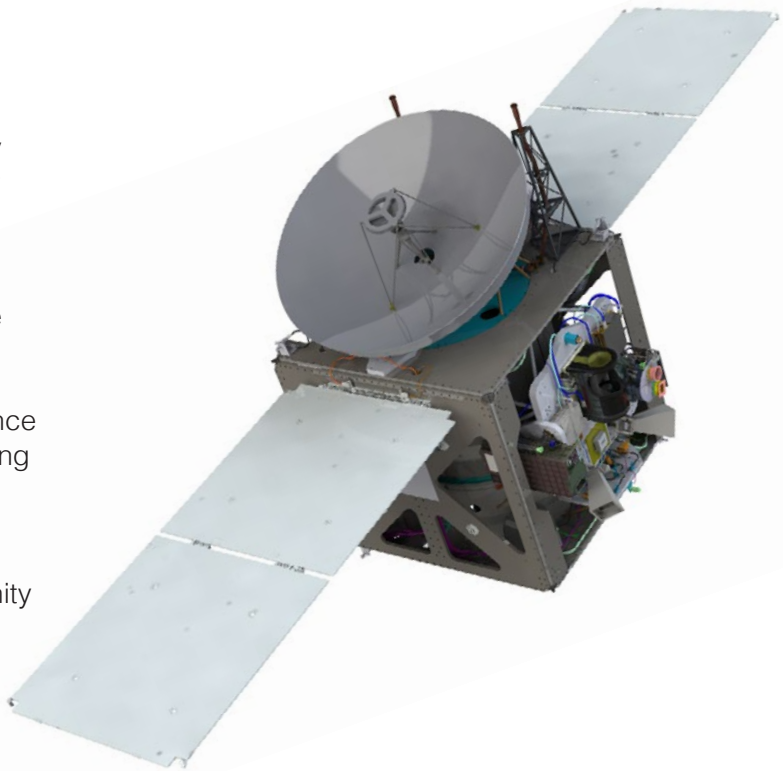


Figure 3. Global evolution of ideas of the value of space missions

Transformative value

While other nations have used space programmes as inspiration and catalysts for domestic change, the UAE's initiation of the EMM as a national priority project is especially distinctive and notable in two regards: first, for its strategic intentionality; and second for the scale of learning and development involved.



Nations' primary motivations for initiating space exploration missions, and the subsequent framing of their value propositions, have changed over the decades. From the importance of pursuing scientific discovery, to strengthening national security, to initiating technological spill-over and economic multiplier effects, to investing in observation and data sharing infrastructure, the international space community is now increasingly framing investment in space-based scientific and technological capacities as a means to grow national economies. The UAE's intentional envelopment of each of these motivations within one single principal aim to turbo-charge its national transformative capacity is impressive and may well be unique.

The EMM is also remarkable for the scale and pace of learning and development involved. Continuing from a short decade of initial satellite and astronaut programmes, this mission is not the UAE's first space-oriented activity. Yet a journey to Mars has different requirements to journeying a little beyond the Earth's atmosphere. The technical and programmatic complexities involved differ by orders of magnitude. Outer space missions operate in environments where a single part vibrating can affect the entire satellite; equipment can be a thousand time more sensitive to electrostatic discharge; and flight control works with multi-minute time lags. In order to reach Mars, the UAE has needed to rapidly leapfrog more gradual development activities into some of the lowest tolerance and highest requirement space activity there is.

Looking for evidence

Combined, this suggests that the experiences of the EMM programme could offer useful lessons not only for those involved in space exploration, but also for those broader communities interested in the ways that missions generate transformative value for society.

It is this latter interest that brought together University College London (UCL) and the Mohammed Bin Rashid Space Centre (MBRSC). Founded in 1826 with a history of radical thinking aimed at transforming society through knowledge production and engagement, UCL is a world-leading university with strengths across a wide range of disciplines and domains. At its Department for Science, Engineering, Technology and Public Policy (STEaPP), it undertakes research and analysis about the ways by which national policy can enhance the societal benefits of investment in science and technology.

In line with STEaPP's broad ambitions, over the July-October 2019 period, the MBRSC engaged it to independently review the impacts of the EMM. This report is a synthesis of the discussions that followed with the MBRSC staff about value of space missions, a desk-based exercise reviewing relevant evidence from around the world, and multiple meetings with the EMM team, as well as a wider range of stakeholders and global experts, including the primary EMM project partners at the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder, the EMM's Strategic Review Board, and former NASA experts.

This study asks: what evidence is there is of any transformative value initiated? What impacts is the mission having, and what value is it generating, where, how and for whom?

What this report does not do, however, is ask questions about the cost of space exploration missions, or whether the related allocation of resources is justified. These are important questions that benefit from access to studies that investigate the value generated space missions. Academic work underpinning this analysis will subsequently be published separately and publicly.

All about timing

It is worth noting the timing for the MBRSC to invite for an evidence-based review of the value generated by the EMM.

This study was undertaken as the programme is still in its preparatory phases, and the Hope probe not yet launched. Most space mission impacts are usually observed post-launch. It is the MBRSC's pursuit of impact in the form of transformative capacity that encouraged and motivated a value study this early in the process. Our early findings are hereafter presented in 2 parts:

I. Principles for Transformative Value Analysis. This provides the background for the approach taken for the value analysis.

II. Impact of the Emirates Mission to Mars. This summarises the evidence collected of value generated by the EMM.

7 principles for transformative value analysis

> Counting dollars in and out is the wrong thing to do when thinking about the value of space missions. The UAE perspective on the long-term societal value of missions is the only way that makes sense.
>
> **Charles Bolden**
> NASA Administrator
> 2009-2017

Given the world's long-time engagement with questions of why, or whether, we should explore space, it is surprising to find that there have been few comprehensive value analyses of deep space exploration missions. Much more common in the space sector are studies of the value of Earth-orbiting satellites (such as communication and observation satellites). Their fundamentally different nature and purpose, however, limit their direct utility for assessing the impacts of space exploration missions instead.

There is also no single preferred method for valuing a space mission. A range of studies use various methods and apply starkly contrasting boundaries on the scope of activities considered. What could we do instead if we were to start with a blank canvas?

Drawing on the experiences, lessons and recommendations made by previous value studies, seven principles are shared to inform a more comprehensive analysis of transformative space missions. The resultant 'Transformative Value Canvas' summarises a new approach for measuring space mission impact developed by the UAE's EMM work programme.

1. Value the whole spectrum

The value created by space missions spans multiple domains, from technological advances to new institutional processes. This makes it impossible to comprehensively capture that value if only considering individual sectors or activity types. Yet ideas about value are significantly influenced by historic studies that have sought to express the benefits stemming from space programs in terms of "return on investment" through cost savings, cost avoidances and new revenue streams.

While compelling, these types of narratives conceal that space missions are about more than an economic return on investment: they are about broader, more crucial societal return on investment. A different approach is needed in order to consider the whole spectrum of returns, including non-monetisable impacts such as new knowledge generation, additional technological know-how, and a changed sense of identity.

Figure 4. A broader spectrum of impacts to capture comprehensive mission value

2. Measure with more than numbers

There is an understandable analytic presumption in favour of measuring value with numbers. This preference is encountered in many areas of policy and programme evaluation, and is mirrored in the space domain. Reported evidence of space mission value has typically focused on enumerating technological innovations and commercial benefits. As previously pointed out, the nature of impacts is often less tangible and eludes a quantitative analysis. This is especially pertinent in the early stages of a space mission. A multi-source approach combining early quantitative data as well as a qualitative analysis of experiences and learning, changes in perception and motivations can bypass these limitations.

Figure 5. Mixed approach with impact data types

3. Anticipate long-term benefit

Impacts from research and development activities usually evolve and emerge over different time scales. Whereas new know-how and skills might be developed and visible within a year, the transfer of technological innovation into other sectors could take several years. The transformation of a national economic profile or the emergence of new educational pathways can unfold over a decade or longer. A multi-timescale analysis of mission value anticipates these evolving impacts across different near-term, medium-term and long-term time horizons.

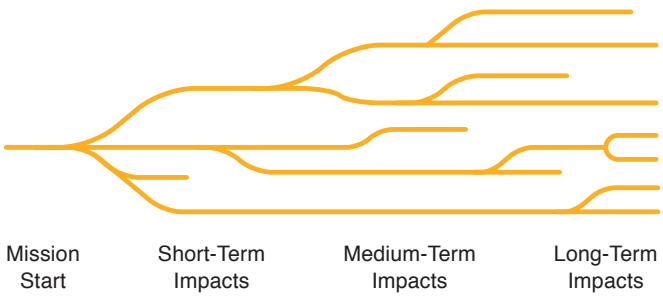


Figure 6. Time lags for different types of space mission impact

4. Reveal influential mechanisms

When impacts are not easily observed and captured, or may not happen until a more distant future, evaluation scientists recommend collecting evidence that validates the existence of the causal mechanisms required to generate those impacts. For example, we might anticipate increased future uptake of science postgraduate degrees ('impact'), but not yet have the evidence. Until that evidence becomes available, it is possible to test claims for this future increase in postgraduate degrees ('impact') by collecting evidence of the EMM's role in changing perceptions about science ('context'), and work with universities to increase the availability of science education pathways ('mechanisms'). This explicit articulation of causal linkages leading to impact provides a foundation for improved long-term tracing and attribution of the mission impacts.

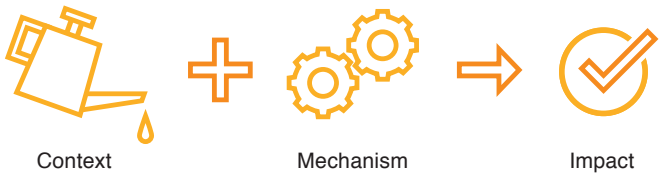


Figure 7. Evidence for causal impact claims

5. Trace multi-domain impact

The impact of a space mission such as the EMM goes beyond pushing the boundaries of scientific knowledge or contributing to the growth of the space economy. It also contributes to national development via innovation, institutional capacity, and to international visibility and global engagement effects via diplomatic and security interest channels. These are critical parts of a holistic picture of value, yet seldom collectively captured in space mission evaluation studies.

Figure 8. Multi-domain mission impacts

6. Capture transformative value

Space missions generate long-term impact in a variety of ways. Traditionally, missions are understood to either strengthen existing capacities (e.g. improving precision manufacturing know-how), supply additional capacities (e.g. a new clean room facility), or transfer value into non-space domains by 'spilling over' ideas and know-how (e.g. using acquired data science skills in the renewable energy sector).

There is, however, an additional mechanism for impact that does not neatly fit into these previous traditional categories. It is the impact a programme has in building capacity to transform an economy, and enhance its future capacity for value creation and innovation. A comprehensive value analysis should therefore look for evidence of all four impact mechanisms.

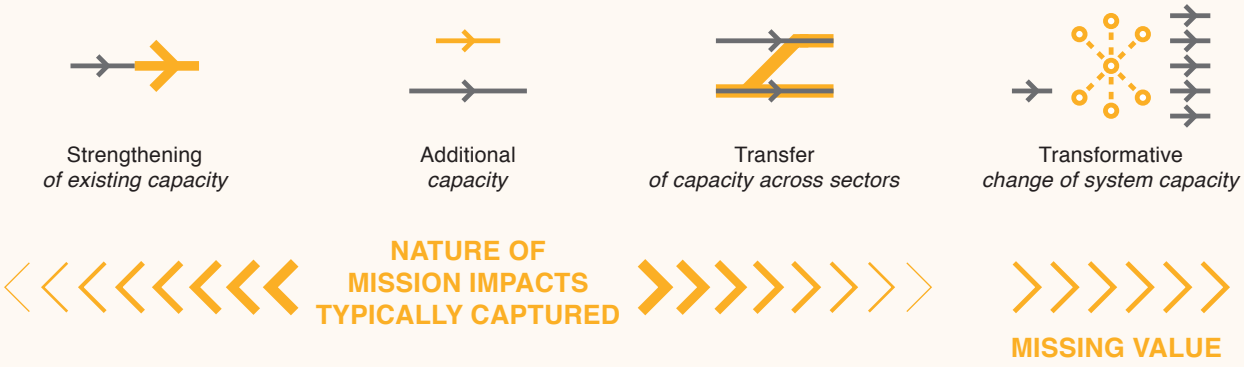


Figure 9. Multiple natures of mechanisms for mission impact

7. Account value with new methods

The two most influential and widely used evaluation tools are cost-benefit analysis (CBA) and macroeconomic input-output models. Their use in space studies typically acknowledges their limitations in properly enabling operationalisation of the principles shared so far in this section. The space community has therefore issued multiple calls for innovation to overhaul the evaluation methods used for space missions. In response, a new tool has been specifically developed here to enable an early-stage analysis of the impacts of the EMM: the Transformative Value Canvas.

See next page for new comprehensive value method

A tool for comprehensive value analysis: Transformative Value Canvas

When can I use this?

You can use this canvas as a checklist for thinking through the full spectrum and diversity of impacts that space missions have. This can be used during early stage mission scoping in order to inform strategic decisions, as well as throughout a mission's lifetime to structure impact assessment exercises. It was used in this study to structure a database recording EMM impacts and to facilitate early identification of patterns in the data. In future we hope the Canvas can help prompt ideas about how the value of space missions can be further enhanced.

How do I use this?

The Transformative Value Canvas prompts a user to consider three complementary 'perspectives' to capture the comprehensive value generated by space missions. These three perspectives reflected the best practice principles presented in the previous section.

Domain of Impact

Trace impact across a range of domains. For the EMM impact spanned across advancements in scientific capacities, to changes benefiting the UAE and international space economies, to the UAE's wider national development, as well as its changing global opportunities.

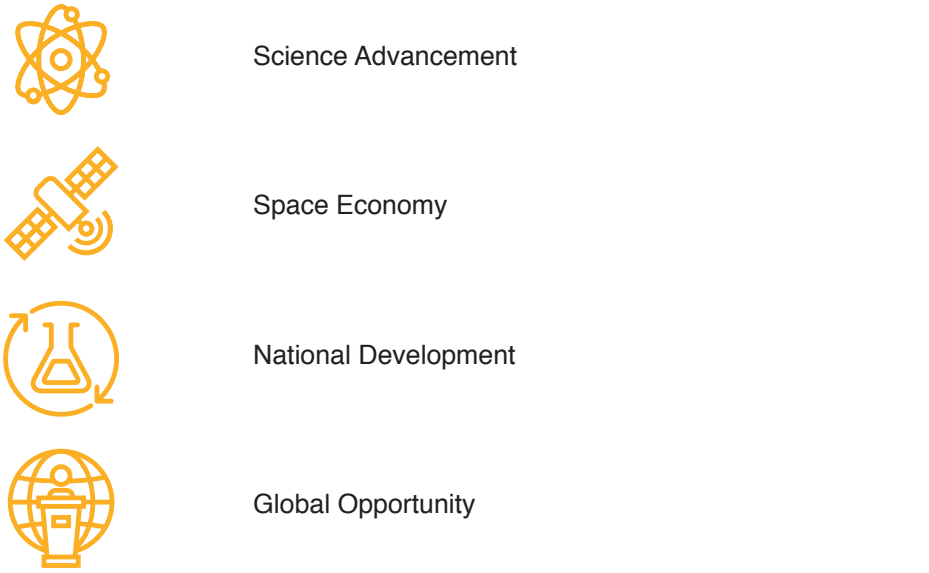
Type of Impact

Capture a broad spectrum of impact types. The sixteen types embedded within the Canvas reflect those championed and reported by space impact studies, as well as more diverse impacts identified in the evaluation of national transformation initiatives.

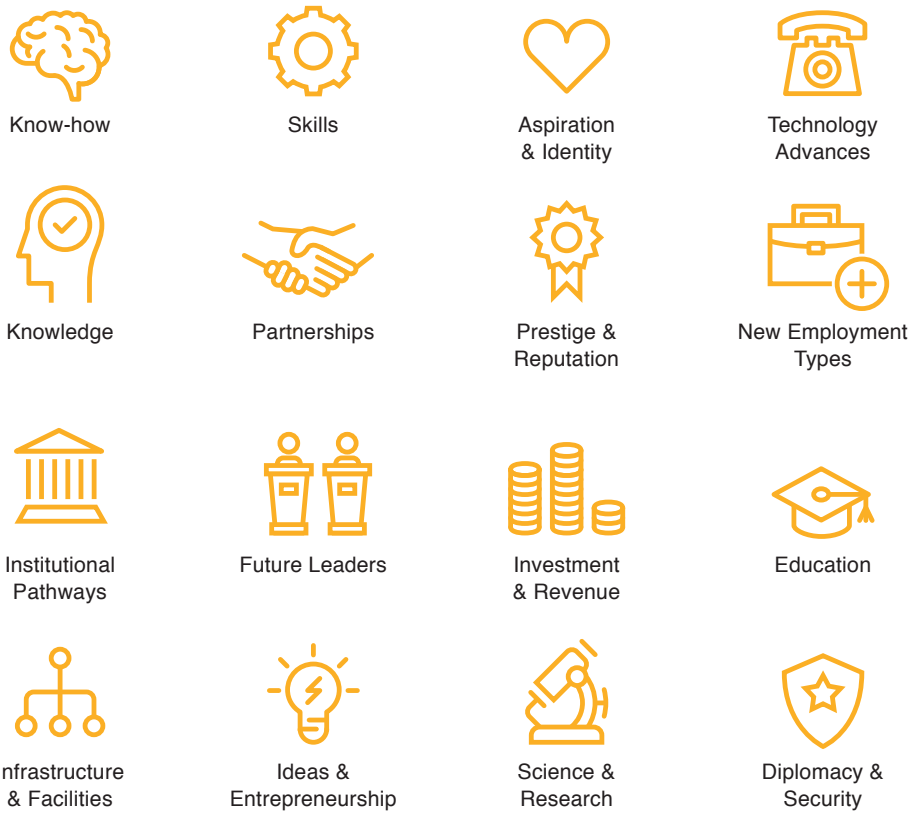
Nature of Impact

Consider multiple mechanisms of impact. While many studies focus on strengthening, additionality and cross-sector transfer mechanisms for impact, also scan for impact generated from transformative mechanisms.

Domain of Impact



Type of Impact



Nature of Impact

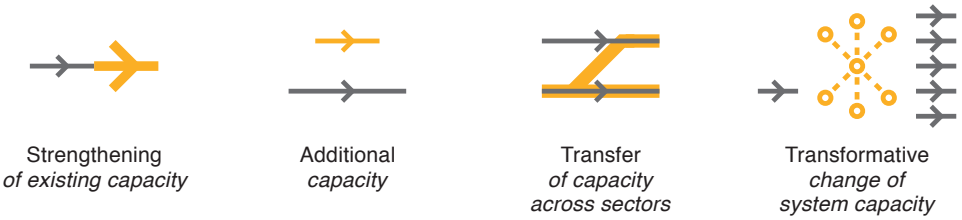


Figure 10. Transformative Value Canvas

Part 2: The Value of The Emirates Mars Mission

Snapshots of impact

What impacts

Since the mission announcement in 2014, what range of impact has the EMM had on the science, space economy and the UAE's national and global development capacities by October 2019? (Capacities extant in 2014 are illustrative).

2014

MBRSC
Earth observation capacity
Telecommunications satellites
Engineering education base
Data science skills

2019

Diplomacy & Security	UAE reputation for openness to collaboration UAE reputation for space capabilities
Prestige & Reputation	UAE science diplomacy capacity Enhanced attractiveness of MBRSC as contracted partner Knowledge transfer mechanism from US to UAE
Future Leaders	100K+ social media followers 20+ confident future leaders for transformative action Highly transferrable skills for public and private sector Experience working with international colleagues Bilateral agreements with 4 world-leading universities
Partnerships	Partnership with Gulf Extrusion Partnership w/ University of Colorado Boulder (LASP) Grant programme for space science Faculty hires for planetary science Publications in space science
Science & Research	Scholarships for Emirati research students MBRSC Science department established MBRSC Lab at Dubai University Rise in public interest in science Work ethic and culture enhancements Rise in scientific literacy Attractiveness of science degrees Spread of culture of research amongst Emirati students Science Apprenticeship Programme
Education	Schools engagement programme More undergraduates for UAE S&T sector New undergraduate pure science programmes Research Experience for Undergraduates Masters students in Physics
Technology Advances	PhD science researchers Space science in Ministry of Education curriculum Scientific ultraviolet & infrared technology
Investments & Revenues	Emirati start ups in field of Advanced S&T SMEs programme Capacity for outer space missions
Ideas & Entrepreneurship	Emirates Data Centre Clean room facilities High precision instrument development
Infrastructure & Facilities	Greater readiness for next space activity Advanced project management standards Risk management standards
Knowledge	Quality assurance capability for space products
Know-How	Enhanced skills in software quality assurance Resource allocation model Definition of science mission requirements
Skills	High grade parts manufacturing know-how Open source Linux capacities 4,500 new design, scientific, technical documents

Figure 11. Range of impacts since 2014 mission conception

Who benefits

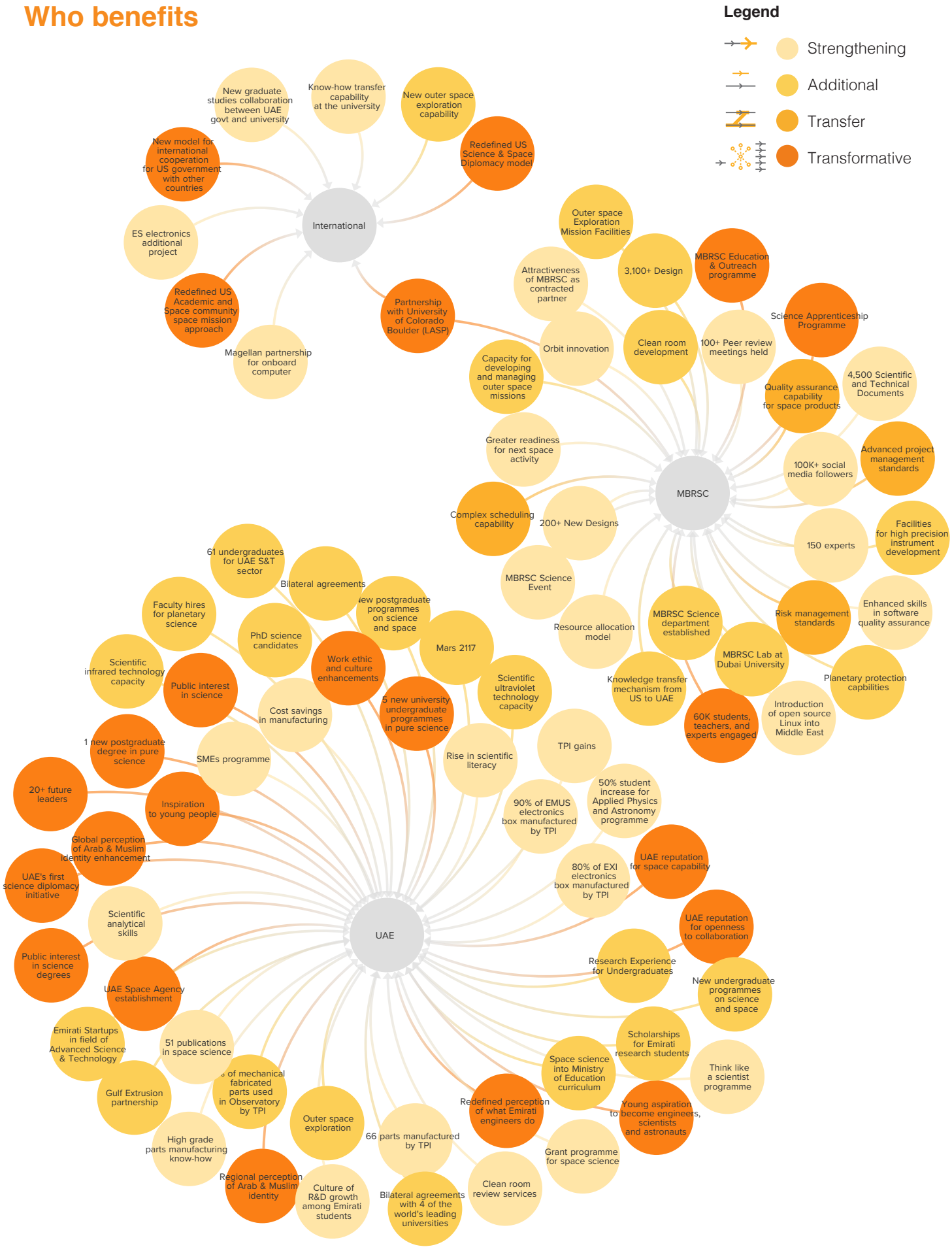


Figure 12. Some EMM impacts to date clustered by primary recipient of value generated. The recipients considered include space-specific (MBRSC), national (UAE) or international beneficiaries.

Where

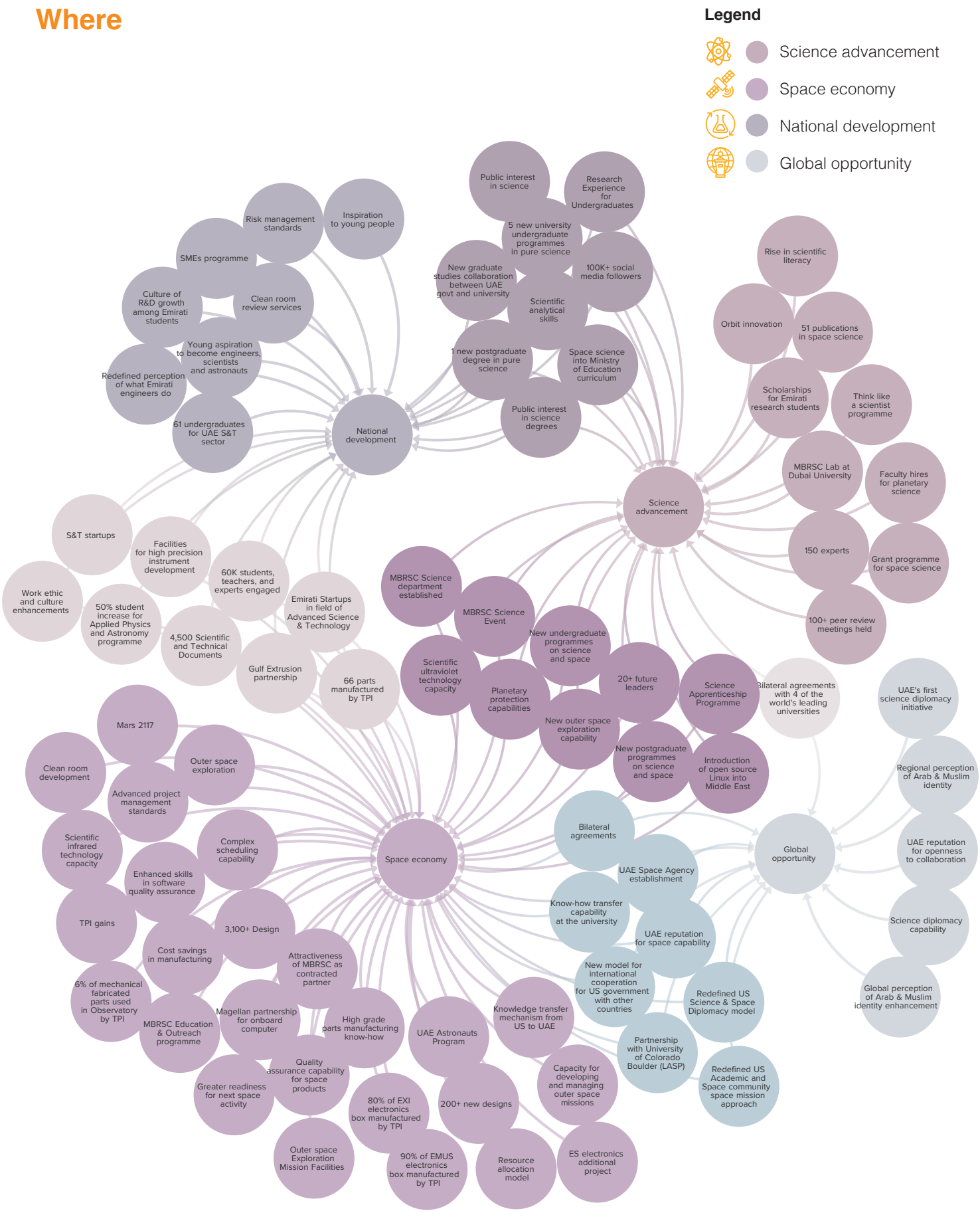


Figure 13. Some EMM impacts to date clustered by the primary domain locus of their impact, categorised by: space science, space economy, national development or global opportunity.

Science advancements

Highlights

- UAE emerging as regional space science leader
- Remarkably fast development of space mission capacity
- Momentum for new scientific qualifications
- Doubling of student numbers on some applied physics degrees
- ‘Emirates Data Centre’ sets high international standard in open science

> The engagement of the international community with the EMM team at the major annual science events tells what positive impact they are already having.

Dr David Brain
Space Scientist
University of Colorado at Boulder

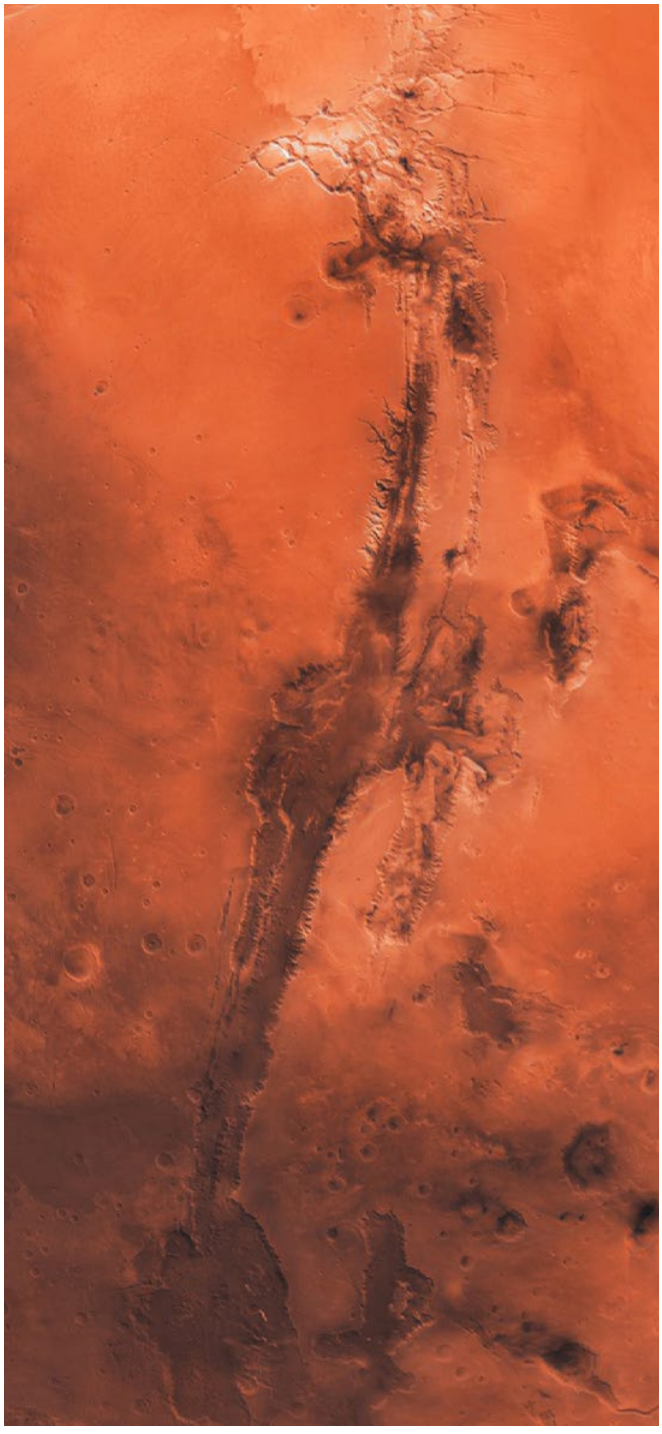
Unlocking the mysteries of Mars

By providing regular atmospheric measurements across a range of locations and about different layers of the Martian weather system, the EMM will generate new knowledge about the planet's climate. The value of such knowledge is about more than elucidating the workings of foreign planets. Indeed it is possible that enhanced insight into Mars' atmosphere could help us better understand our own. Data about Mars' eroding atmosphere or its lengthy sudden dust storms may lead to new and crucial knowledge about the Earth, from the role of aerosols to behaviours of extreme events in atmospheric models.

Expedited space science reputation

The mission aims to build an Emirati reputation for space science. The programme team is currently working to make it possible for the mission's activities to result in internationally reviewed journal articles led by Emirati scientists. However, the point of departure to meet this goal posed a challenge just a few years ago. There were no Emirati Martian atmosphere scientists. In fact, there are very few Emirati planetologists, only a small community of deep space scientists, and certainly no pre-existing global reputation for cutting edge space science.

Yet there are already signs that this reputation is in the making. As reported by external peers only a few years later, Emiratis are now perceived as a cohort to take notice of and the UAE as an emerging regional leader in space science. The number of papers accepted to international conference presentations (more than 50) and the earnest reception the Emirati delegation received at Ninth International Mars Conference offer a few tangible indicators of this shift.



Fast-track Emirati science

This reputational boost is the result of a successful effort to develop Emirati space science capability of different actor groups within an incredibly tight time frame. Given that the EMM team has had only six years available before the set launch date, and that space missions of comparable magnitude led by senior space scientists often take more than a decade from conception to launch, this is a real tour de force.

Faced with high constraints in terms of time and pre-existing human capital, the EMM programme chose to draw on its internal team resources to meet some of the needs for new science capability. An 'apprenticeship' programme saw staff 'apprenticed' into atmospheric and other science areas, in addition to their regular jobs. Considering that the minimum standard to be qualified in defining and managing novel scientific research activities leading to peer-reviewed journal publications typically take four years full-time[1], this is again noteworthy.

Emerging research ecosystems

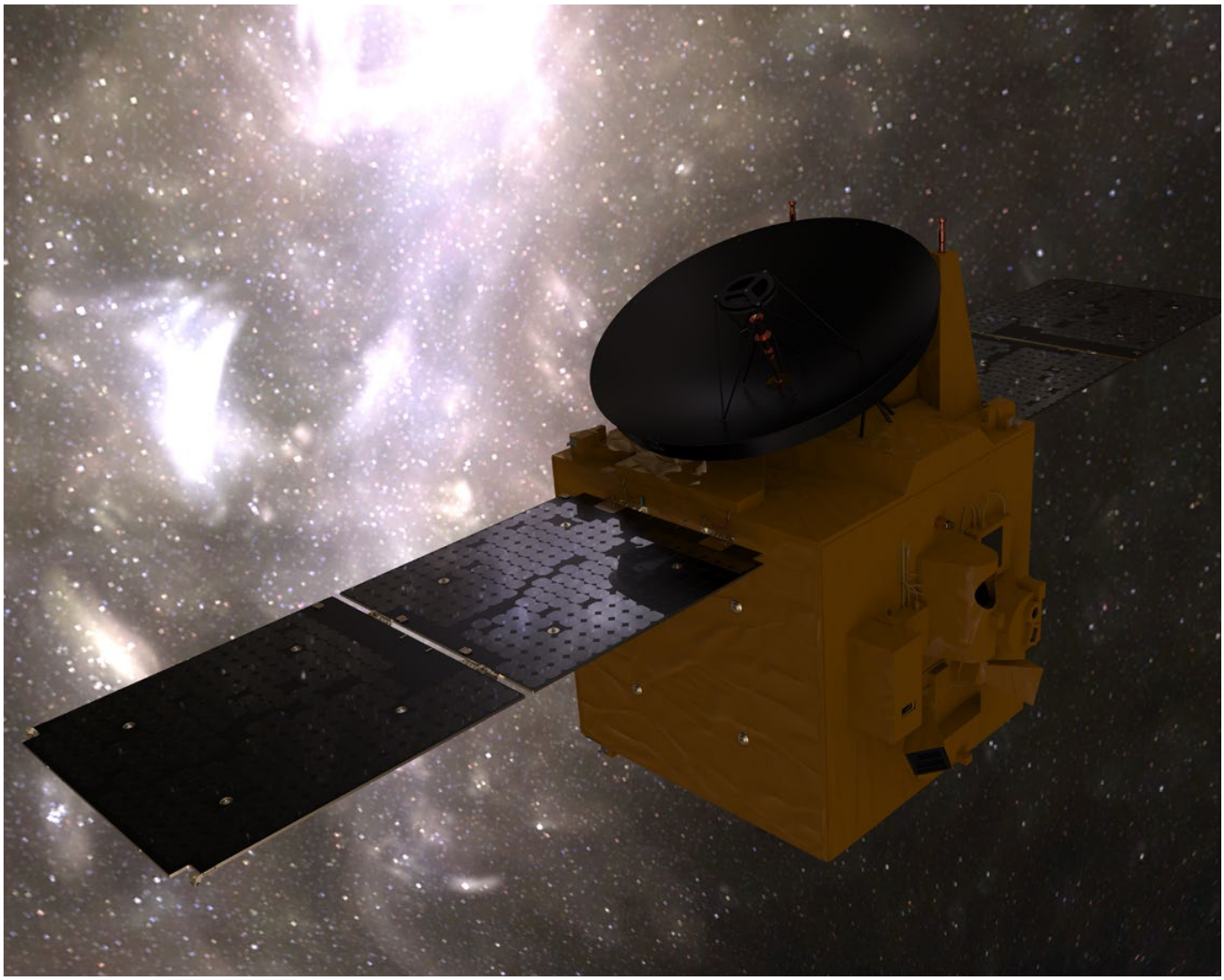
The programme has also dedicated significant efforts in developing the overall national science capacity, especially when it comes to nurturing young (science) talent. In combination with its considerable educational outreach programme aimed at schools, the EMM has engaged with universities to create momentum for new scientific degrees and qualification.

For example, the University of Sharjah Department of Applied Physics and Astronomy reports that student numbers have doubled since the inception of the EMM programme.

At the undergraduate level, the EMM has initiated the first UAE 'Research Experience for Undergraduates' (REU) programme. The REU comprises a competitive selection of young engineers and scientists to undertake international research placements with a reputable space scientist. The programme has developed the UAE's relationships with some of the world's leading universities, including the Sorbonne University and Arizona State University. Positive feedback by both the students and international university partners about the resultant research has been recently validated with instances in which international partners are now specifically offering scholarships for Emirati students to extend the impact from the REU projects and participate in international space science events.

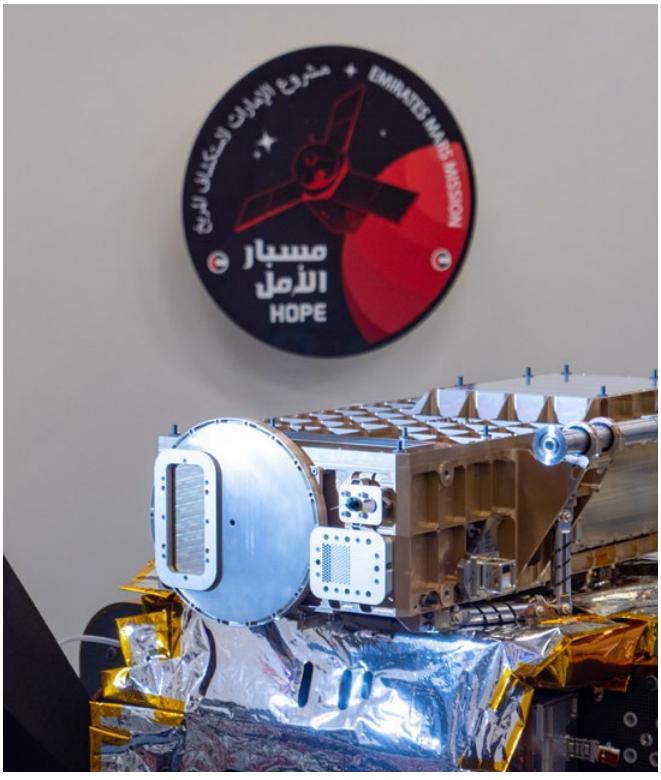
The mission has also experimented with several mechanisms in order to foster collaboration with its own national universities around science mission concepts. Early catalysts have been multiple science community meetings, and the first national grant funding programme for Emirati principal investigators working on space science topics. These activities have already contributed in building connections between different hubs and research nodes. These efforts combining actions at the primary and secondary level education curriculum with the development of national and international scientific collaborations, as well the introduction of stable sources of funding for both pure and applied science, create the necessary conditions to instil confidence in the long-term viability of scientific careers in the UAE and attract future research staff and students.

1 This assumes scientific research design and management qualification to doctoral level.



Data resource for the UAE and the world

The EMM is also participating in the development of national and international science capacities by virtue of its mission data. Hope's data will be released to the public and global science community via a live, open access infrastructure, releasing updates without embargo period via the "Emirates Data Centre". This approach is not only important in ensuring more widespread use of the scientific data, it also sets high international standards in open science. Ongoing work between the MBRSC and universities to develop domestic capacity to use that data will also assure local benefits. Indeed, new data science and programming skills as well as high volume data management and dissemination expertise acquired as a result of this specific space science and atmospheric data analysis can easily be transferred to other space activities or even applied to sectors as diverse as agriculture, transport or finance.



Space economy growth

Highlights

- On budget and ahead of schedule is almost unique achievement
- New national high precision production capacities
- Introduction of new international logic for strategic space mission design
- Significant human capital developed for future programmes
- Enhanced international perception of UAE as attractive space partner

> We should not underestimate the journey that the MBRSC team have been on, from a place of education and theory with limited practice, to the point where they now have the tacit knowledge and experience to hold their own within the global aerospace community. Their potential is, truly, limitless.

Brett Landin
EMM LASP Spacecraft Lead
University of Colorado, Boulder

Growth and future preparedness

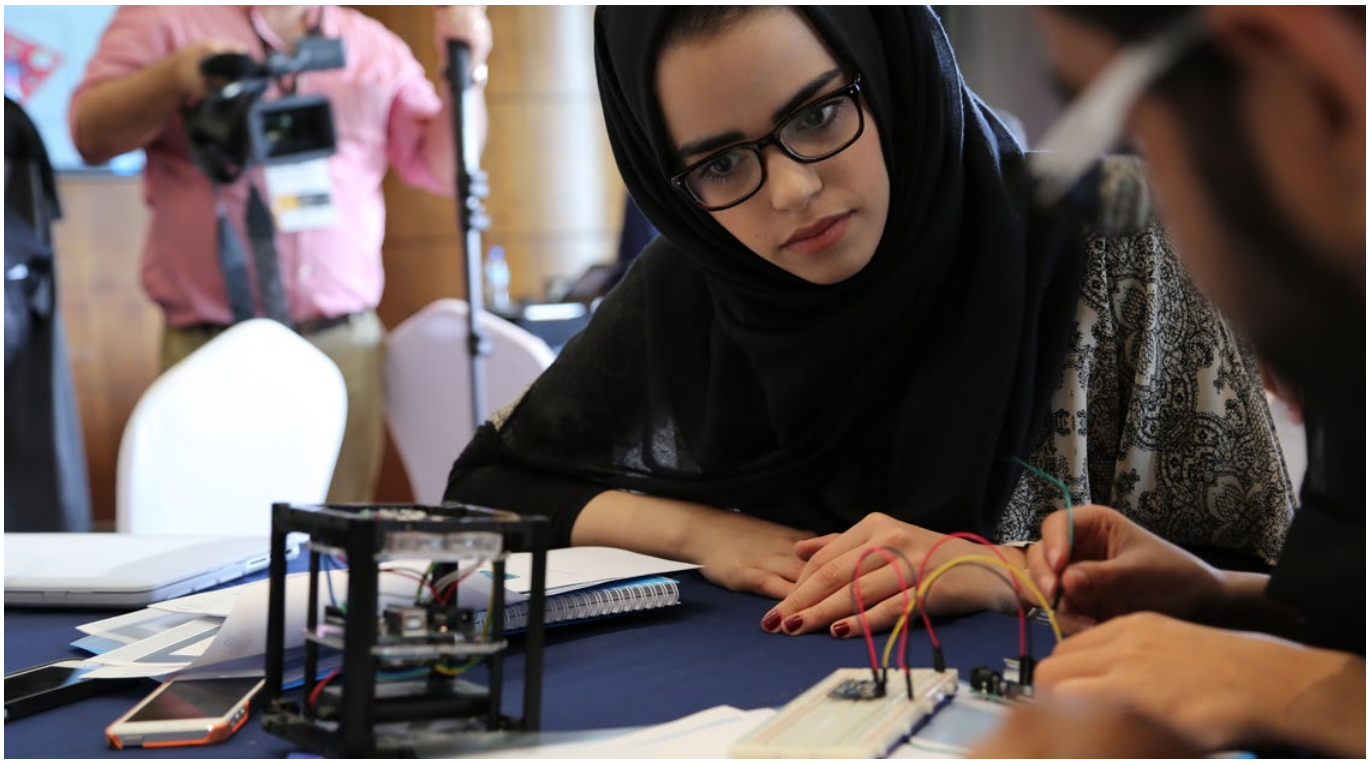
A challenge faced in expanding any space economy is the high transition cost in significantly enhancing space-related capacities. A step-change in sector growth often requires a step change in the level and capacity for product and service quality produced (for example, shifting from geocentric orbits to more complex missions requires new production capacities of special anodised and heat-treated materials). Yet the demand for these highly specialised goods and services categories can be low, one-off, and unprofitable. Without serial production, critical mass to support the growth of national space economies is impaired.

ith high infrastructure requirements for launch and communications, space exploration missions have often involved a high degree of international cooperation to distribute the investments required to attain that critical mass. The MBRSC has been able to use the EMM as an opportunity to cost-effectively collaborate and learn from international partners, in order to enhance its domestic space capabilities and subsequent preparedness for future space activities.

Enhanced space capacities

The EMM has provided investment in capital infrastructure and facilities for the UAE's space economy. This includes a high specification 'clean room' for the production and testing of highly sensitive equipment within precise temperature, pressure and humidity-controlled environments. It is the first large clean room built for space activities in the UAE, developed 100% in the UAE by Emirati companies. Subsequently, there is now domestic, specialised knowledge about large-scale clean room design, maintenance and operation, of particular relevance for the high-humidity, high corrosion risk environments found in the UAE and its surroundings. The team has already been approached to share this knowledge with universities building clean rooms for their specific work with drones and cube satellites. In the near term, this may also prove useful for other business sectors, such as the automotive industry.

The capital developed for future space activity extends beyond physical assets. The EMM has also advanced novel aspects of simulation software, as well as capacities for reusing mass memory codes on future missions. The introduction of open Linux systems for mission command has introduced both greater flexibility for future missions, as well as greater cost-effectiveness by reducing licence fee expenditures.



UAE attractiveness as a space collaborator

The future role that the human capital developed as part of the EMM can play is not to be understated. Most of the ~40 core mission delivery team members are very young (with an average age under 35) and 34% of the team are women – the highest such ratios on recent missions worldwide. Each team member has undergone significant training in new skills and problem-solving capacities for their work, including mission cruise flight school, new programming languages, database design, open science infrastructures, hardware design, electronics testing, complex space project management, risk management procedures, diplomatic engagement and so on.

Combined, these enhanced space-related capacities and a reputation for speed and cost effectiveness have already enhanced the comparative attractiveness of the UAE as a potential collaborator or supplier on space programmes both regionally and internationally. These emerging reputational impacts are reflected in the EMM's unprecedented ability to attract the former heads of four space agencies to the region.

Industrial spill-overs

Since its inception, the EMM has contributed to, and benefited from, a step change in the UAE aerospace manufacturing capacity. Following concerted efforts to find local partners and working closely with them to support new design and manufacturing processes, over 80% of structural components of two of the critical payload instruments onboard Hope have been manufactured by Emirati firms.

Space exploration components have very narrow tolerances, demanding very high precision in the design approach, machine strategies and handling of material. While an aerospace manufacturing base was already present in the UAE, there is now additional know-how about very high tolerance requirements via, for example, learning in machine strategies with coolants and spin speed. This enhanced know-how for producing higher grade parts can potentially spill over into other sectors in region and save business actors manufacturing time, translating into cost reductions. Several companies have already reported a broadening of their customer base following engagement with the MBRSC on the EMM, including Emirates Sky Cargo, Allied Transport Company, Gulf Extrusion and TPI. Further work is needed to develop additional pathways facilitating broader engagement and shared know-how development with the private sector.

New partnership logic for global missions

An absolutely indispensable component of the EMM's rapid learning and capacity development has been its partnership with the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder. LASP is a global centre of excellence in space research and development, and long-time contributor to NASA missions.

Whilst administratively more complicated and practically challenging at times, the decision to team up with LASP as a mission partner on basis of culture and shared objective of learning over technical capabilities only (as is often case when engaging a traditional aerospace contractor), has allowed the EMM to simultaneously develop domestic capacity, as well as benefit from a collective, global skill set. It has also contributed to significantly lower costs compared to a traditional space programme. With a much lower contingency budget than NASA missions (5% versus 20%), the EMM programme also is on budget and ahead of time, an almost unique state of affairs in space programmes and one recognised internationally. This project approach, grounded in a strategic partnership logic and framed around know-how transfer, now offers an innovative, demonstrated philosophy for delivering space missions.

Impacts on wider space economy

One further impact on the wider regional and global space economy is the success by the MBRSC EMM team to get its scientific spacecraft removed from the International Traffic in Arms Regulations (ITAR) list. Indeed, ITAR - the US regulatory regime that restricts export of defence-related technologies - includes the space domain. The team pursued this in order to develop the UAE knowledge base, though this ease on export control may also have further bilateral benefit in possible positive impact on the US space industry, enhancing their global commercial competitiveness.

National transformation

Highlights

- Foundational know-how and knowledge for economic diversification
- Growth stimulus for pure science tertiary education
- Wide spectrum of skills development transferable to non-space sectors
- Multiple new risk management, human resource and knowledge management tools developed

> Being part of the research related to the Emirates Mars Mission makes me proud. It excites me. It's something that I can do for my country and its future.
>
> **Young Emirati REU researcher**

Diversification of economic foundations

In order to provide a secure and sustainable future environment for its residents, a UAE national priority is to diversify away from a predominantly oil-based economy. In the form of a scientific space programme, the EMM serves as one mechanism for catalysing that transformation. Space, as a sector and programme context, thereby serves as a means to an end in several important ways, rather than the end in itself.

Critical to that national transformation is the diversification of the country's economic capacities. Beyond a diversification of the primary economic resource, these transformative economic capacities comprise diversification in the UAE's knowledge bases, diversity in skills bases, diversification in career pathways, as well as diversification of the institutional and governance structures to enable collaboration between different societal actors. Some of the necessary competencies exist already, of course, such as in the areas of finance and financial services, but others are in further need of systematic development support.

Science futures

Science and research-based capacities have been identified by the UAE government as an important component of that diversified national future. Science and research development cover a diverse user base, linking into capacities for a range of sectors including energy, entrepreneurship, finance, health, and public service improvement. EMM-driven transformation of the UAE's scientific capacities thereby goes beyond the field of space science. Early evidence from university staff and students suggest that the EMM is providing a growth stimulus for pure, non-space science tertiary education. In the last two years, five universities have initiated new science undergraduate courses, while other already existing science degrees have reported increases in enrolment figures. Some students have identified UAE space activities, including the EMM, as their inspiration for their degree choices.

One enabler of this significant shift has been the extensive EMM's Outreach & Engagement programme. Numerous events and activities for families and schools have encouraged

young people to take interest in science and technology, and have to date reached about 50,000 secondary and primary school students, and approximately 1,000 teachers.

A historic challenge for UAE science has been a widespread societal impression that science and research degrees lead into little other than teaching employment routes and university roles. Engineering has traditionally been perceived as a considerably more flexible and reputable career choice than careers in science. The outreach programme, widespread engagement with the achievements of the first Emirati astronaut, as well as ongoing EMM media pieces, are now, however, challenging those perceptions.

Leaders for transformation

The capacity for UAE economic transformation is not only supported by the increasing availability of new educational and research pathways for future graduates. The EMM is also contributing with additional transformative human capital by virtue of its team, who have grown as a cohort of leaders capable of driving transformative change.

The experiences, knowledge and personal development gained by EMM team members is transferable to complex programmes outside of the space sector. It is a resource available in the near-term for engaging confidently with emerging market, technology and business opportunities. EMM team members have demonstrated not only new knowledge and skills, but also a high work ethic, critical problem-solving mentality, comfort in dealing with unfamiliar challenges, and important experience in working internationally. The resultant comfort and confidence to act as leaders was noted by their international peers during a 2018 UAE Ministerial visit to LASP. It will be necessary to identify opportunities for that leadership to find continued areas for impact post-EMM, especially in the delivery of the objectives of the 2071 plan. Specific opportunities might arise in the involvement of EMM personnel in the National Laboratory and seizing the opportunities presented by Expo 2020 to demonstrate UAE's science diplomacy capability.

Know-how & tools for change

A final, valuable locus of the transformative capacity instigated by the EMM is in the know-how that has been developed throughout the programme. Many of the operational know-how and related tools, processes and lessons that have been developed and tested in EMM and MBRSC, such as complex Project Management, Human Resources and Risk Management have wider applicability, both across government and in the private sector. Specifically, the team developed new tools for risk management, human resource allocation, knowledge transfer management, and management of large volumes of data. It managed this know-how capacity with a new internal infrastructure that keeps track of all lessons learnt. This has already been made use of by others wanting to engage in unfamiliar and ambitious projects, such as the Jumeirah group, Road Traffic authority, Government Science and Technology plan team, and the Country Innovation Week.

Global opportunity

Highlights

- UAE demonstrator of 21st century cutting edge science and technology
- Catalyst for diplomatic and international science engagement
- Positive focus for Arab and Islamic identity
- Invaluable EMM reputational effects

> “At a time of considerable regional uncertainty, the manner in which the EMM project is being conducted reflects the UAE’s increasing regional leadership and appetite to grasp opportunities. In doing so it is enhancing its reputation for international collaboration and playing an increasingly influential role in the wider global economy.”
>
> **Admiral Sir Trevor Soar** KCB OBE DL
> Commander-in-Chief, Fleet, UK Royal Navy
> 2009-2012

Shifts in the sand

Over the past fifty years, the Middle East has been predominantly reliant on vast hydrocarbon resources to drive economic development. Ongoing global energy market changes, as well as shifts across the relative diplomatic influences within the region, have prompted MENA countries to adpat new development mechanisms in pursuit of long-term prosperity and security.

Amidst these changes, the UAE is positioned to increasingly provide stabilising diplomatic leadership and it has envisaged a considerably more substantial role for science and technology to shift towards a knowledge-based economy. Besides shaping an economic capacity advantage, science and technology have also been identified as effective platforms via which to enhance the UAE's international engagement and diplomatic clout. The EMM as a high-visibility endeavour therefore simultaneously both advertises, as well as supports, the development of those emerging scientific and global engagement capacities.

Beacon for the UAE and the region

In enhancing the UAE reputation as a space actor, the EMM propagates national, regional and international narratives of a nation spearheading innovative science and technology programmes. Nationally, the EMM has specifically been employed to broadcast a message to Emirati citizens that "you too can be part of building the nation for the future". As the EMM makes the UAE only the sixth nation to attempt to reach Mars, it reflects as a highly visible, yet friendly competition with the leading superpowers in space. This has significant potential to change some of the ways by which its citizens situate themselves within a global context.

Regionally, some have observed that the EMM also offers hope for the renewal of a long tradition of astronomy contributions and that it may act as positive source of wider inspiration to the 200 million young Arabs in the region. It is thereby used as a vehicle to advertise the feasibility of combining ambition with tolerance, and provides a positive focus for Arab and Islamic identity transcending national borders.

Changing the international narrative

Space science and space exploration comprise forms of scientific knowledge largely perceived as value-neutral in comparison to other areas of scientific development (e.g. artificial intelligence for its potential workforce displacement issues, or nuclear physics for its military applications). As a disciplinary field and sector, space exploration's focus on advancing human knowledge about the wider universe is deeply transnational and may further contribute to changing international perspectives about the region.

The value of these reputational effects of the EMM should not be underestimated, irrespective of whether the Hope probe makes it to Mars. There is evidence already of the EMM's positive impact on the UAE's global reputation for collaboration and openness and in several instances international scientists have already approached the EMM team specifically because of that reputation.

Science diplomacy catalyst

Science is a known instrument for international relationship building and diplomatic engagement. Though science diplomacy is nascent in the UAE, the EMM is laying the requisite foundations.

The EMM has introduced new, strong bilateral space science relationships, untethering it from a historic dependence on South Korean capacities. Its membership to the International Space Exploration Coordination Group (ISECG) provides direct diplomatic access to fourteen of the most prestigious space agencies around the world. Association with such prestigious groups can provide diplomatic spillovers into other areas of science or global fora for the UAE.

Finally, the EMM has demonstrated that the UAE has the will to contribute to issues of scientific importance, as well as demonstrated its ability to develop the human intellectual capacity to engage in new, global scientific challenges. The EMM has therefore strengthened the UAE's potential to make global contributions to the challenges and issues of tomorrow.

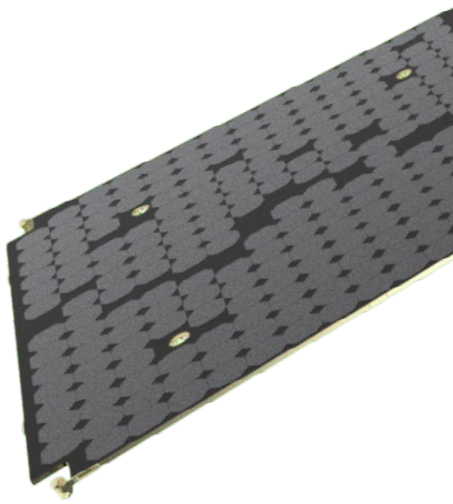


Figure 14. International relationships fostered via EMM

Final note

Valuing and sustaining transformative impact

The Emirates Mission to Mars is impacting the UAE's space science capacities, as well as its space economy, national development, and global engagement capacities. Undoubtedly it is not the only national effort contributing towards these types of outcomes: there are several other ongoing efforts across the UAE to develop its scientific and space-oriented capacities. Yet the evidence suggests that the purposive and targeted allocation of effort by the EMM in the capacity-developing initiatives described in this report has been instrumental in driving the nature and pace of changes observed - and likely to be further experienced over coming months and years. The EMM is a remarkable contribution to the efforts pursuing transformative value for wider UAE society.

As these are still early stages in the EMM's influence, more work will be needed over the coming months and years to collect evidence to validate and clarify the actual scope of its impact. Looking ahead, we conclude that significantly greater societal value could be accrued still if the transformative capacity nurtured by the EMM is proactively engaged with wider UAE leadership.

Opportunities need to be provided for the mission's know-how, human intellectual capital, facilities, partnerships, and other outcomes to be made use of and further developed. Whether this is better attempted via the means of another space mission or another scientific and technological innovation initiative remains an open question.

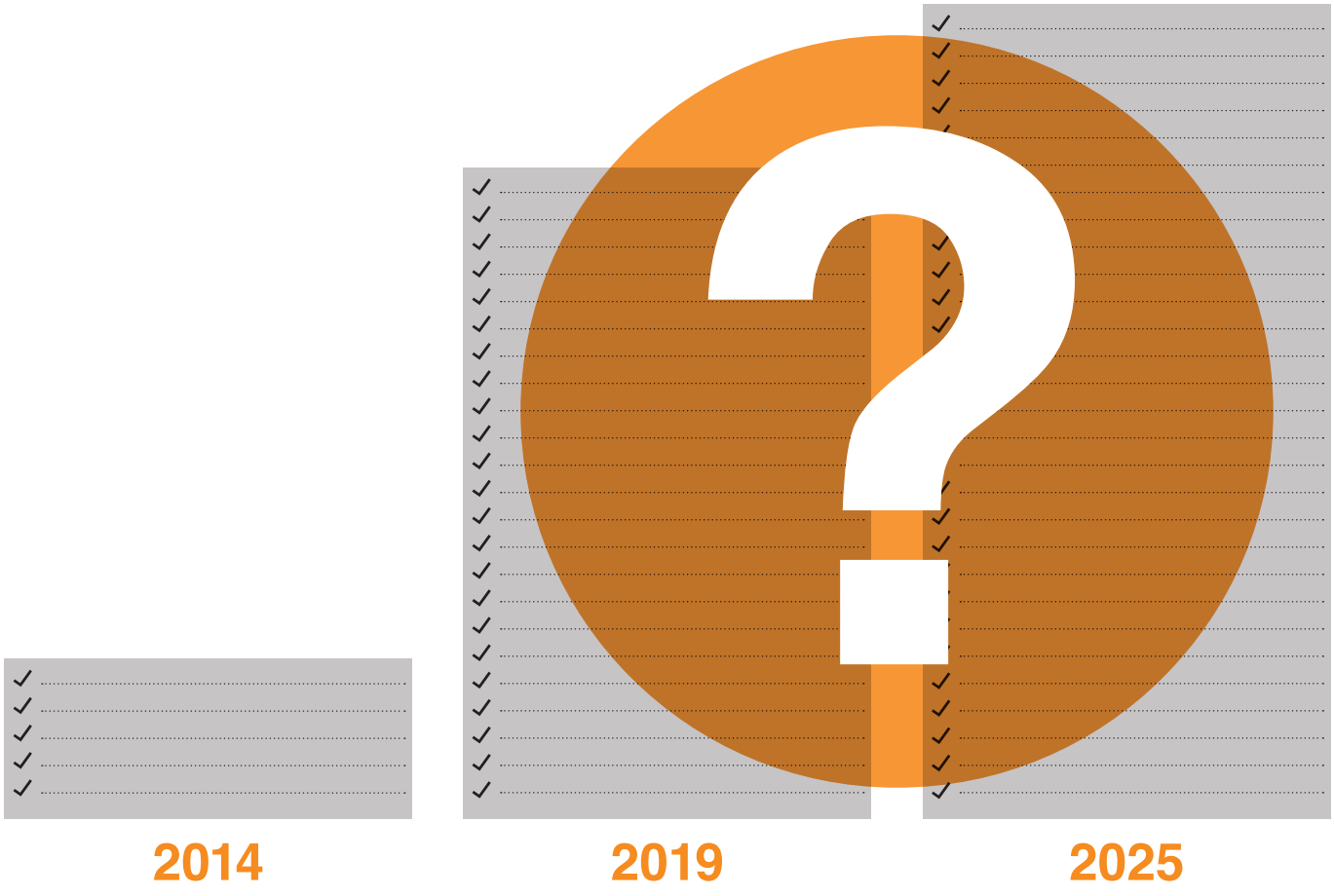


Figure 15. Transformative value for the future

Annexes

A. Methods used for space mission evaluation

Method	Key methodological aspect	Monetary valuation	Notes on degree of use and comparative limitations
Impact Assessment	Separate treatment of impacts	N	Multiple examples, all with different boundaries on e.g. sector and geography. *+ explicit treatment of diverse impacts* *+ direct, indirect, induced effects can be included* *+ non-economic can be included*
Multi Criteria Analysis	Scoring and weighting of different criteria of assessment	N	Used to evaluate policy options and investment, and benchmark activities. *+ captures effects that are hard to measure or monetise* *+ can be participatory* *+ separates weighting and scoring on impact criteria* *- often faces (misplaced) criticism of invalid subjectivity and lack of rigour*
Input-Output Analysis	Model of interdependencies between different sectors of a national economy or different regional economies to show impact on GDP	Y	A few studies *+ Direct and some indirect effects* *+ Standardised data sources* *+ Explicit causal links* *- No external effects* *- Limited space sector specific data* *- Intensive to set up*
Computable General Equilibrium Analysis	Whole economy simulation (e.g. capital, labour, commodities, consumption) that looks for economy-wide impact. Often aggregated input-output tables	Y	No example study applications known to this study's authors. *+ Captures direct and indirect effects* *+ Could capture some external effects* *+ Explicit causal links* *- Data demands for input-output to capture space activity impact* *- Rarely includes external effects such as spillovers* *- Non-inclusion of non-quantifiable*
Cost Effectiveness Analysis (& utility, etc)	Comparison of options using single indicators. Variations in terms of what range of objectives considered	Y	One CEA study known to this study's authors *+ non-quantifiable can be accounted* *- indirect effect not accounted* *- use of single measure*
Social cost benefit analysis	Form of CBA that considers distribution of effects among stakeholders. Assesses willingness to pay for each impact	Y	Several studies, most on GMES. Most do not include direct effects on space sector, nor external. *- focuses on monetisation of effects* *- valuations of non-market impacts are difficult* *- outputs difficult to interpret*
Social Return on Investment	Special case of social cost benefit analysis. Stakeholders define what the most important sources of value are	Y	No known applications to this study's authors *+ participatory* *+ includes societal and environmental benefits*
SCBA-plus	Combination of cost benefits analysis and social return on investment	Y	No known applications to this study's authors *- requires both objective measurement and money valuation*
Real options valuation	Used to make investment decisions when future is uncertain. Used in R&D budget allocation	Y	Not yet seen applied on actual project.
Balanced scorecard	Performance management tool		No known applications to this study's authors *+ monetary and non-monetary measures*

Figure 16. Overview of methods that have been identified as applicable for assessment of the impact and value of space missions (adapted from Clark et al. 2014)[3]

[3] Clark, J., Koopmans, C., Hof, B., Knee, P., Lieshout, R., Simmonds, P., & F. Wokke. 2014. Assessing the full effects of public investment in space. *Space Policy*, 30(3), 121–134.

Approaches to space activity evaluation and assessment are either:

- Ex-ante (prospective) or ex-post (retrospective).
- Bottom-up (where each effect is measured separately and aggregated) or top-down (where a framework is provided that already integrates the effects).

In terms of the methods used for assessment, many studies use traditional techniques such as econometrics, input-output multipliers and cost-benefit analysis. More recently there has been a trend towards exploring the use of social cost benefit analysis and social return on investments. Figure 16 on the facing page provides an overview of the methods primarily identified for assessment of space activity value.

B. Data sources and collection methods

Project activity	Journal papers	External reports	Space agency reports	UAE documentation	Interviews
Count	30+	10+	20+	4	44
Mapping impacts	X	X	X	X	X
Classifying into framework		X	X		X
Operationalising via metrics	X	X	X	X	X
Identifying data sources			X	X	X
Collecting evidence				X	X

Figure 17. Data sources and collection methods used for study

DEPARTMENT OF SCIENCE, TECHNOLOGY, ENGINEERING AND PUBLIC POLICY

UCL

Dr Ine Steenmans

Ine focuses on analysis that enhances the future robustness of policies. Her work combines and adapts methods and processes from a wide range of fields, including policy foresight, design, and systems analysis, and seeks to improve their usefulness and usability by policy makers.

Dr Jean-Christophe Mauduit

Jean-Christophe has 10 years of experience in astrophysics research and worked on ESA and NASA satellite missions. Over the past 5 years he has been focusing on scientific development issues and science diplomacy research. He is a member of the IAU, AAS and AAAS.

Prof Joanna Chataway

Jo has more than 20 years of experience in the areas of innovation and social and economic development—particularly in the analysis and evaluation of investment in research and innovation, including what sorts of instruments translate research into useful innovation.

RADM Neil Morisetti

Neil has over 30 years of experience working for the UK government, including as Commander UK Maritime Forces and in the Foreign & Commonwealth Office. He is an Associate Fellow at Chatham House and member of the Military Advisory Board of the Washington DC think tank CNA.

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