Sustainability and Circularity Challenges in Aerospace Engineering Education for the Sustainability transition

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for the sustainability transition

by

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Preface

Antony Joseph Valiaveetil
Delft, August 2022

At the outset, I would like to thank God (in three persons) for the opportunity to pursue a Master's degree at TU Delft. I would like to thank my parents, Joseph and Nency for their sacrifice, hard work and trust which I can never repay. I would like to thank my grandmothers, Theresia, Mercy and Lily for taking care of me selflessly. My sister, Sanjana and brother-in-law, Jeffin have been my support throughout this course. I wouldn't have done it without them. I wish to thank No. 18 and Dawndale as well. I wish to thank my grandfathers: two Antony's, who were trendsetters in their own right, for their blessings. I want to remember everyone who I've lost in the last two years especially Francis Varghese, V. M Abraham and Issac Vijaykumar (my second fathers).

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Executive Summary

The aerospace industry and TU Delft have set stringent climate goals for themselves and with each passing year, these goals seem all the more implausible. The reason for the introduction of these goals is due to the impending extinction event: Anthropogenic Climate Change. Aviation is the fastest way to fry the planet and the most sustainable alternative to flying is to stop flying. However, the current trends in the aerospace industry show no signs of abatement and in fact, indicate a steady growth in the potential of aviation. As more people become economically stable worldwide, they tend to fly more frequently. Currently, less than 20% of the world's population has ever taken a single flight in their lifetime. However, around 1% of the world's population contribute to almost 50% of carbon emissions from commercial aviation. The effects of these emissions are experienced by the whole world, unfortunately. While there is an ethical implication to flying, the consensus is that there needs to be a change in the way the industry functions. In other words, the aviation industry needs to become more sustainable.

As aviation brings economic prosperity, opportunity and political importance to a nation, its negative effects were often neglected. However, with growing demand for flying, increased emissions worldwide and global warming looming on the horizon, sustainable practices are welcome in this industry. Novel propulsion methods, critical materials and other technological advancements are being researched as we speak. The question remains as to whether these pathways are enough to address the climate goals. While sustainability in the aerospace industry is envisioned as futuristic, circular, net-zero aircraft, the change rarely comes from the grassroots. Although these technological solutions are undoubtedly our liberators from long-term climate change, there is relatively less focus on the education of engineers who grow up to design these machines. This is the primary focus of this thesis and a participatory approach has been followed to instil a sustainability-oriented attitude among the students of aerospace engineering at TU Delft. Since circularity and the circular economy is a means to achieve a sustainable industry, this has been addressed as well in the study.

This thesis follows a bottom-up approach which can stimulate pro-environmental attitudes among future aerospace engineers to give ourselves a fighting chance to mitigate climate change. This approach is clubbed with an Action research method to gain insights from students' perceptions of various obstacles which are identified in the industry. A sustainability module which incorporates circularity is developed for the course under study and hence this provides an improvement to the existing course. The United Nations Sustainability Development Goals are employed in this process and as this involves a minor curriculum change, Bloom's Taxonomy is invoked to develop the module. The research then collects quantitative and qualitative data on the perceptions of students towards the obstacles. This data is analysed for correlations and insights which can be used for future research. Additionally, a focus group is subjected to in-depth lectures and sessions which are aimed at developing a pro-environmental attitude which can have positive effects on the course, but more importantly in the real world.

Finally, the implications of the study are discussed and recommendations are provided. The limitations and scope for future work are analysed by concluding the data collected. The generalizability of the study is discussed and the options for developing other courses from different faculties are discussed. Sustainability learning goals are developed for use for future courses at Aerospace Engineering as well as other Faculties. As the education of engineers, in general, is an important aspect of the way our world takes shape, the relevance of this study is important, particularly in the area of sustainability. Hence, this thesis is a small portion of the larger picture that is Climate Change. While it must be noted that a single pathway alone cannot fight climate change (as it is a wicked problem), collaborative efforts across all fronts need to be made. This study focuses on the aviation sector and the education of aerospace engineers in specific.

Keywords: sustainability, circularity, Mixed Methods, Action Research, Bottom-up approach, pro-environmental attitudes, aerospace engineering education, TU Delft.

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Acronyms

AE Aerospace Engineering

AE1222-I Course Code Project

ASM Aircraft Structures and Materials

AWEP Aerodynamics, Wind Energy and Power & Propulsion

CE Circular Economy

CfS Center for Sustainability

CO Control and Operation

COP26 Conference of the Parties

CRM Critical Raw Materials

EASA European Union Aviation Safety Agency

ECTS European Credit Transfer and Accumulation System

EOL End-Of-Life

FAA Federal Aviation Administration

FPT Flow Physics and Technology

IEPS Interdisciplinary Education Perception Scale

ITL Interdisciplinary Thesis Labs

LCA Life-Cycle Analysis

LDE Leiden-Delft-Erasmus Universities

LR TU Delft Faculteit Luchtvaart- en Ruimtevaarttechniek

MoT Management of Technology

MOOC Massive Open Online Course

MRO Maintenance, Repair and Overhaul

NLR Nationaal Lucht- en Ruimtevaartlaboratorium

NVAO Nederlands-Vlaamse Accreditatieorganisatie

OEM Original Equipment Manufacturer

PhD Doctor of Philosophy

SDGS Sustainability Development Goals

SE Space Engineering

SWOT Strengths, Weaknesses, Opportunities, Threats

TA Teaching Assistant

TBM Faculteit Techniek, Bestuur en Management

TUD Technische Universiteit Delft

VSV De Vliegtuigbouwkundige Studievereniging ‘Leonardo da Vinci’

Contents

1

Introduction

The global population is currently increasing at around 1% per year and this trend is expected to continue for the remainder of the first half of the 21st century (O'Neill et al., 2002; UNDESA, 2022) [1]. This means there is going to be an increase in the global demand for food, shelter, energy, healthcare and transportation to name a few. All these basic needs require an immense supply of raw materials to maintain a standard quality of life. Every aspect of human life requires spending energy and raw materials to obtain products and live life without compromising comfort, well-being and prosperity (Orr, 2012; Bish, 2020).

The primary factor which defines the economic development of a region is transport (Hoyle, 1973). Ever since the dawn of the industrial revolution, humans have used steam power to get to places fast. This spurred economic growth and improved standards of living as it facilitated trade and enterprise across various parts of the globe (Banister, 2012, Spike Aerospace, 2017). As we progressed through the 1800s, transport was much more readily available to the masses in the form of ships, trains and cars. With technological advancements, we managed to improve the speeds at which these vehicles travelled. However, it was not until 1903 that man had finally managed to develop heavier-than-air flying machines. This step drastically reduced travel times from months and weeks to hours. Hence, faster travel directly improved an individual's life, health, status and well-being in society. Coincidentally, this also acted as a catalyst for countries to emerge as developed nations as fast transport directly translated to expending more energy, which was a statement of the technological prowess of a country (Logsdon, 1997).

Around 70 years and a couple of wars later, humanity made it to the moon and this step involved a large amelioration of existing technical knowledge and scientific advancements (Pop, 2011). After this, we arrive at the present day where we are extremely reliant on travelling large distances to carry out our daily routines, run our businesses and make strides in advancing our careers. All across the world, we are highly dependent on fast transport to meet our needs and to get to places as and when we wish and require. In fact, the dependence on transport has helped us build bridges as people, grow substantially as a race and has provided several other boons which would otherwise take us years to set up and develop (Loo and Banister, 2016).

However, this dependence on transport also has an unfavourable side. The capitalistic principle of infinite growth has caused humans to neglect the adverse effects of fast transportation (Næss, 2006). While this effect is not caused only due to transportation, it contributes to a big portion of the problem. This problem is Global warming. From the dawn of the industrial revolution, human beings have burnt fossil fuels to source their energy to run machines, obtain electricity and sustain transport. This chemical process releases a host of harmful compounds which cause the earth's atmosphere to heat up at a rate faster than the earth's nominal rate of climate change. This anthropogenic climate change is directly related to the burning of fossil fuels and this was accelerated through man's quest for faster

[1] The projections are around 9 billion by 2050 (Roser, 2013)

transport, advancements and a comfortable lifestyle (Peter, 2018).

As the speeds of transportation increased, so did their reliance on fossil fuels. This problem of accelerated climate change due to human activities was not foreseen when we started using fossil fuels for quick transport. However, in hindsight, we observe that we have contributed to an almost 0.2 degree rise in the earth's temperature every decade from the late 1800s to 2010. This perfectly represents a Collindridge Dilemma where the negative effects of burning fossil fuels cannot be reversed today as we have all largely benefited from it (Genus and Stirling, 2018). The fastest means to get around the world today is by flying. It also is the fastest way to fry the planet (Lee et al., 2009; Schauffler, 2018). The contribution of aviation corresponds to around 12% of the emissions from the transport sector. This number may seem small, however, the numbers do not tell the whole story because most of the emissions are released at an altitude of around 35000 feet which causes a lot more damage as the area covered is significantly higher. Additionally, the aviation sector contributes to around 2.1% of global carbon emissions. However, this does not take into account the non-carbon emissions which also play an important role in escalating the greenhouse effect. All in all, aircraft, as a means of transport, have contributed to around 4.9% of the world's radiative forcing since its inception (CAN and ICSA, 2018).

It is a well-known fact that while aviation and fast transportation cannot go away completely, they must be promoted in such a way that their dark and colossal impact can be reduced as much as possible. There are currently a large number of researchers who are actively investigating novel propulsion methods, (TU Delft) like hydrogen and electric propulsion. There is also a lot of research being done in areas like critical raw materials, manufacturing processes and using cutting-edge techniques to reduce the environmental impact of aviation. However, the focus on the future requires multiple pathways and this would also include education of the future aerospace engineers to assimilate the concept of sustainability and its associated significance (Eisenhauer, 2016). As the current Aerospace Engineering (AE) students are tasked with carrying on the flame of innovation into the future, they should be prepared to face the brunt of their ancestors' actions while actively pushing forward as a species. Hence, this thesis is aimed at ensuring that prospective engineers are subsumed with the necessary knowledge.

1.1. Background

Historically, the world has followed a principle of Linear Economy where we take from the environment, make our products and use them (Figure 1.1). This is followed by disposing of or wasting these used resources back on the environment. This cycle follows for every new product and industry on this earth (Stefanakis, 2020). This is unfortunately not a very sustainable means of making our life better because the demand for resources will be greater than the rate at which these resources are replenished by the environment. The effects of a demand which exceeds the rate of supply would be the cause of many unwanted problems like ecological degradation, conflicts and natural disasters and pandemics (Bish, 2020). Hence, to maintain our demand for a better life as a human race, our economic cycle would need to be modified to accommodate the increase in demand without an increase in waste of raw materials and resources. The selected economic model for this transition is the Circular Economic Model (Rodrigues Dias et al., 2022) (Figure 1.2).

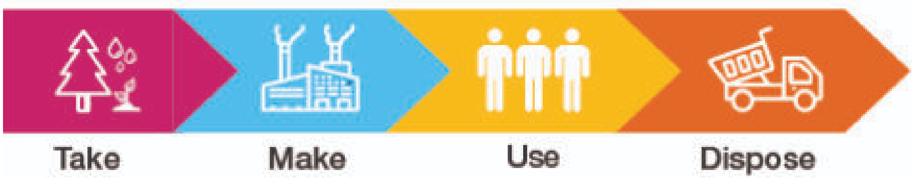


Figure 1.1: The Linear Economic Model as illustrated by Power, 2019

The Circular Economy differs from the Linear model primarily because the pathways of this model incorporate feedback loops into the source which prevents waste and disposal of the majority of the raw materials. Secondly, this model, which is also referred to as circularity, ensures that the raw materials are used at a more disciplined rate which potentially ensures that the negative effects of population increase are not as profound as they are projected to be. Similarly, this way of life is a propounder of sustainable living and can be a solution to climate change and a host of the environmental evils which we humans are responsible for introducing since the start of the Industrial Revolution in the 18th century (Rizos et al., 2017).

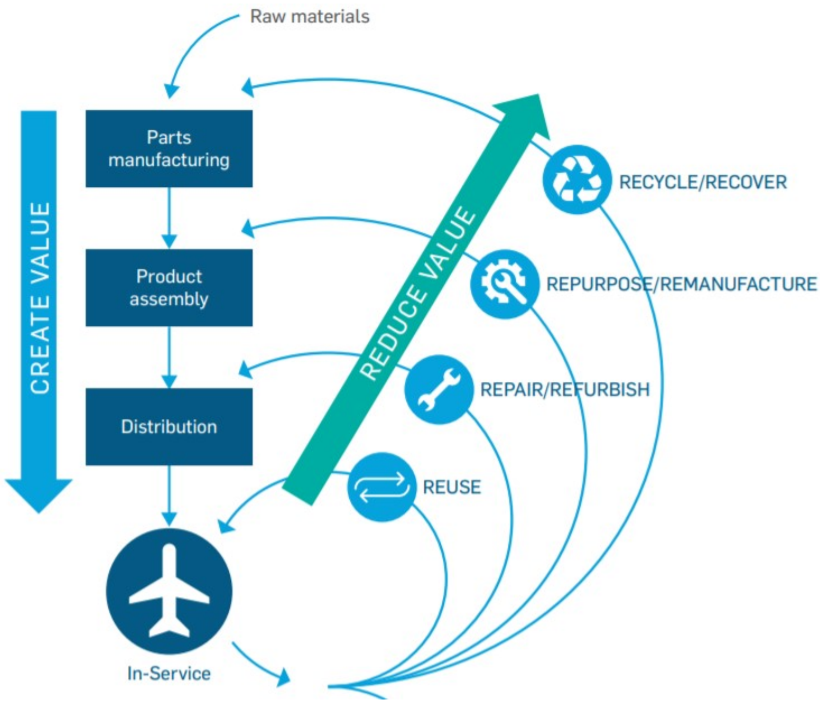


Figure 1.2: The Circular Economic Model employed in the aerospace industry (Domone et al., 2021)

To narrow down my research, the basis of this thesis will focus on the transportation segment and precisely on the Aviation sector. While it is important to incorporate a Management of Technology perspective into this review, the focal point of this document is the adoption of a circular economy in the said Aviation sector. This also includes the military and non-military sectors due to their close association with aviation and flight. Most of the important environmental considerations fail to take into account the contributions due to the defence sector citing confidentiality issues (Weir et al., 2021).

The recently concluded UN Climate Change Conference, Conference of the Parties (COP26), has facilitated the shift of focus of the world to being more sustainable and climate-friendly in our actions (Circular Online, 2021). As part of this conference, a lot of importance has been given to the transport sector and the elephant in the room, which is aviation. While the contribution of aviation to the emission of greenhouse gases is evident and requires a drastic reduction, the focus of this thesis is more on the raw materials which are used and the life-cycle of these materials (and finished products) which are required to conform with the circular economy. On average, the world uses 100.6 billion tonnes of material per year and it recycles only 8.6 billion tonnes from the remaining refuse. This accounts for around 13 tonnes of raw materials per person, per year. While transport accounts for 8.7 billion tonnes, it leads to 14.6 billion tonnes of material wasted in emissions and 22.4 billion tonnes of material lost to the environment every year (Carrington, 2020). The aviation sector plays a big part in this segment especially due to its staggering 394.5 g CO_2 equivalent emitted per passenger kilometre making it around 2.5 times more polluting than cars (Stay Grounded, 2019). While the CO_2 emissions are not the primary deciding factor for measuring the need for circularity, it has a strong secondary effect which calls for improved focus on circularity in the aviation sector.

While there is a lot of emphasis on circularity in the aviation and aerospace sectors, most researchers argue that the problems related to circular transition are at the grass-root level. This means that by the time engineers are in the industry, they are already too late to help transition to the circular economy. Hence, to further narrow down the area of focus, the education of engineers is this thesis's primary focus. Higher technical educational institutions are the main factories which create engineers who exercise their trade in these above-said sectors. Due to the impact they have in ensuring a circular transition, they will be researched in depth and the trends and challenges will be studied. With technical education, the focus lies mainly on aerospace engineers[2].

This is where we chance upon a 'technical mindset' which is inherent in most (aerospace) engineers. This refers to the mentality which is imbibed in engineers due to which their primary focus is fixated upon delivering the best possible products without giving any importance to circular practices. The mindset involves being able to produce high quality daily. This is evident in the students who take up this challenging course in most parts of the world. Most times, aerospace engineers are required to undergo a rigorous course which makes them critical about everything they do to improve efficiency, performance and overall quality. This mindset is one of the key reasons why circularity is absent in the aerospace sector.

This thesis is being carried out in the Circular Aviation Lab of the Centre for Sustainability. This is the LDE Centre which comprises the Leiden-Delft-Erasmus Universities. This particular lab was set up to accelerate the transition toward a circular economy (LDE, 2022). This lab works on the fundamental principle of interdisciplinary research which can fuel a systematic and holistic research approach. Hence the three Universities, which offer a plethora of courses in various disciplines join forces to assist education, practice and realignment of higher education towards circularity. The influence of stakeholders and the industry is invaluable, hence, there is sufficient interaction with the corporations, research institutes and the government in Zuid Holland. The two main themes of this Circular Aviation lab are as follows (LDE CFS, 2022):

What can the circular economy mean for sustainable aviation?

To what extent is circularity a solution towards net zero-emission aviation?

With these themes in mind, the focus of my thesis is to realise sustainability and circularity in the field of aerospace engineering education. It must be noted that Circularity is a means to achieve Sustainability. While adopting circular practices is not the only way to achieve sustainability, it is an important aspect when it comes to the aviation industry because of the over-reliance of this industry on the usage of metals. These metals make up components which employ energy-intensive methods, often which are unused after the life of the original part. Circularity and the circular economy comprise a lucrative way to achieve our environmental goals and hence the failure of aerospace engineers to adopt these practices is the starting point of my thesis.

1.2. Aim

Currently, there is a huge gap in the environmental aspect of technical education. This is largely because of the focus of technical education on performance, durability and design for one life. This adversely impacts the earth and there is a need for rethinking our entire design process. A systems approach or modular design approach is known to have the least environmental footprint because it can be re-manufactured, reused and even re-purposed into different useful products. This circular model is the only realistic means to achieve the sustainable aviation goals which are looming and approaching at a fast pace.

On analysing the situation, it can be easily noted that these engineers are not educated on sustainable and circular practices during their University. While it is the author's opinion that this education should be incorporated at an earlier stage in a student's life, that is beyond the scope of this thesis. There is a definitive need for this portion of technical education to improve and this is one of the aims of my thesis. I will be working on a Bachelor level Aerospace Engineering course and adopt sustainability

[2]While other technical branches do not fall into the scope of this thesis, they can follow suit with similar methods mentioned in Chapter 2

and a few circular practices.

I would also be aiming to understand the bottom-up approach of adopting sustainability in education which could be applied to all levels of technical education. This will be carried out by developing a framework to realise sustainability learning goals at all levels of technical education. While it would be next to impossible to realise strong sustainability [3] in technical education, it would be effective to optimise the weak sustainability [4] aspect of aerospace engineering.

1.3. Research Question

"How could the education of aerospace engineers be better developed to incorporate circularity in their design?"

The curriculum of an average aerospace engineering student is generally filled to the rafters with sophisticated concepts like fluid dynamics, mathematics and other aspects of physics which are already complicated by themselves. In most universities, it is an unwritten rule that aerospace engineers study the hardest course because of the importance of human safety, circumventing risk and incorporating advanced technology due to the criticality of flying. To add an aspect of sustainability to aerospace engineering education would add increased workload to both, the students and the professors which need to be adequately allocated. Additionally, the focus of aerospace engineering is to teach students about flying machines, their sub-domains, individual processes and how they can be put to use today. In pursuit of this focus, students need to create something of their own to prove their comprehension of the subject. Adding additional modules which focus on the environment and circular processes would not be fully honouring the aim of an aerospace engineering course. It also presents issues like the magnitude of the grade and the amount of effort required among others. Hence, this process would require careful probing of the syllabus, innovative adaption of the course to suit sustainability/circularity and guiding the students through a special program which could imbibe the concepts of the environment from a very young age.

1.3.1. Sub Research Questions

- **SRQ 1: How can a bottom-up approach be a suitable method for developing an attitude among students to facilitate circular/sustainable design?**
  The primary means of implementation of sustainability into education (which this thesis employs) is a bottom-up approach. This method is chosen because the researcher is best suited to make this change via this approach. This research contains a comprehensive analysis of this approach and its advantages concerning the traditional top-down approach. While this approach is central to the discourse, it must be understood that it cannot make a massive difference as a stand-alone pathway. The dream of realising sustainability in design is a goal with multi-fold pathways, each of which requires its own study. In this composition, however, the cardinal idea is to develop an eye for sustainability among students who would potentially use this newly imbibed knowledge to make a difference in their design. The bottom-up approach is, in the opinion of the researcher, unable to reach its potential without the proper use of a suitable research method. Here, an action research approach is followed which further comprises sub-research methods (making it a mixed method study). However, the aforementioned bottom-up approach is the preeminent technique employed to better develop the education system to aid in answering the main research question.

- **SRQ 2: What obstacles exist within the aerospace engineering students that prevents the implementation of more sustainable practices?**
  To realise the full potential of bottom-up approaches to sustainability in aerospace education, it is also necessary to understand why this stream of engineering has suffered this problem in the past. Aviation's contribution to climate change is staggering and this is also seen in its excessive

[3] This involves de-growth of aviation and possible frugal means of living which is against technical education

[4] This involves the incorporation of circularity, adoption of sustainable fuels and using all technological advancements and design techniques to reduce adverse environmental impact

material usage. Additionally, the aviation sector possesses a host of brilliant and knowledgeable engineers who deal with cutting-edge technology which often gets a free pass for its environmental impact. The current aerospace engineers also usually focus on high quality and the safety regulations are extremely stringent. These existing ecosystem trends and the relative volume of people who are dependent on aircraft have caused a delayed onset of sustainability in this industry. Hence to develop future engineers as those who are environmentally responsible and career driven, we must understand the social and personal barriers that these students may face in their industry. As this was not addressed in the past, this subtle understanding is necessary to aid these future engineers' design in accordance with the environment.

- **SRQ 3: What could be a logical framework for the incorporation of sustainability education in all levels of aerospace engineering?**
The curriculum of any existing technical degree requires careful adoption of new sustainability modules to be effective for the future of aerospace engineers. To do so, a careful framework needs to be followed to make sure the course requirements, quality of education and credit requirements are not jeopardised. As most engineers pursue a Master's degree and while some will continue to get a Doctor of Philosophy (PhD), it is logical to ensure that the bottom-up approach to guiding environmental attitudes is continuously revised. This must be carried out in a very relevant, consistent and compelling manner. Additionally, it is of utmost importance to imbibe these attitudes in a manner which is as per the relevant accreditation board. Furthermore, it would be of absolute use if this framework could be adopted across all levels of aerospace education and technical education. As this research is quintessential in the race towards realising the climate goals of the aviation industry, the priority is undoubtedly given to aerospace education. That being said, it is also necessary to realise sustainability education in all areas of technical education as we require multiple solutions to the problem that is climate change.

1.4. Research Flow Diagram

This section presents the overall blueprint for this particular thesis. As this thesis is very fundamental, this research flow diagram (as seen in Figure 1.3) can be referred to understand the various steps which were taken to tackle the thesis. The diagram starts with the development of a course and then different types of data are collected to answer the different questions. The data is analysed after consulting the literature and different obstacles are presented. The learning goals for future courses are also presented in this thesis which can help advance the research pool in this field.

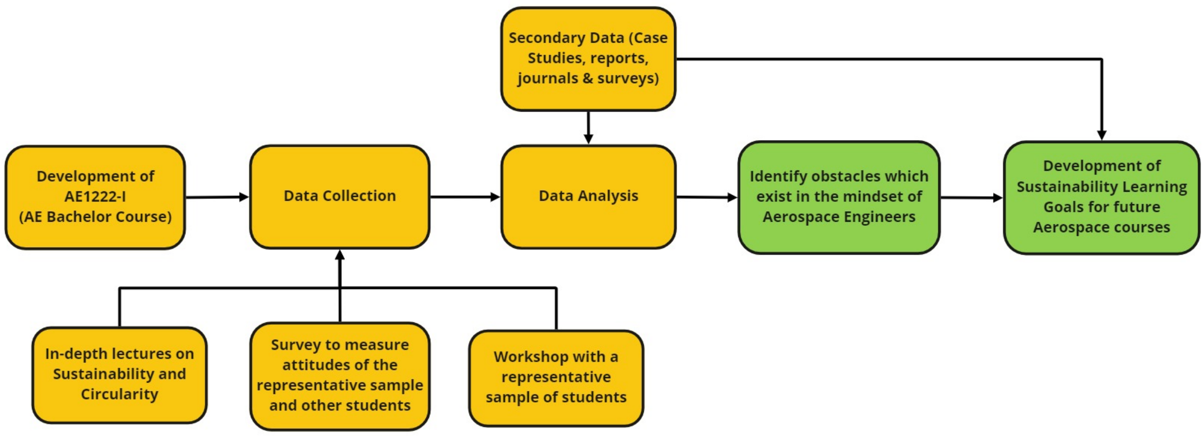


Figure 1.3: Research Flow Diagram: Sustainability in Aerospace Education

1.5. Thesis Overview

This thesis is divided into six chapters and the overall research entails three sub-research questions and one main research question. The first Chapter contains a brief introduction of the context of this thesis and the big problem that is climate change. The contribution of aviation to this problem and the relevance of conducting this research is also presented in this chapter. Chapter two describes how the researcher is tackling the approach of the research. The methods followed to undertake this research are elaborated and the justification of these methods is presented in this chapter Action Research, Qualitative Data Collection and Quantitative Data Collection are the methods followed. In Chapter three, the various literature sources referred to by the researcher and the baselines which have been followed are discussed. The literature is a continuation of the **MOT2004: Preparation for Master Thesis** course which the researcher followed in Q2 2021-2022. Chapter four discusses the results which were derived from the qualitative data and the quantitative data which was collected from the research group. The quantitative data is analysed through JASP 0.15.0.0 and the qualitative data is manually analysed to obtain correlations between the measures. Chapter five presents a descriptive analysis of the results and further implications of the research. The correlations are all drawn out and this chapter also focuses on limitations, and scope for future research and presents the main deliverables which is the goal of this research. Finally, Chapter six presents the conclusions and answers the research questions that are presented.

This thesis contains a lot of additional data which could largely benefit future researchers who are interested in this work. All this data is provided in the Appendices. As the researcher was a part of a thesis lab that tried to find solutions for the larger problem that is climate change, these interactions are also briefly present in the Appendices.

2

2. Research Approach

2.1. Introduction

This chapter will detail the various research methods which will be employed in this dissertation. It describes the distinctive approaches which are used simply because of the fundamental nature of this research. The researcher is keen on making a holistic change in the way aerospace engineers think and perceive their craft. Hence, multiple methods are imperative to this study which ensures that various pathways are addressed to initiate a change. The structure of this chapter has deliberately been portrayed the way it is because of the chronological sequence in which the various approaches need to be understood. However, this complication may be resolved if the Bottom-up Approach is understood as the overarching theme of all the following research methods.

2.2. Mixed Research Methods

As the research questions entail multiple sub-research questions, a mixed method of research is identified to be the most suitable means of exploration. This is also necessary for the reliability of the findings and as the aim is to improve educational practices and make small, effective changes in students' attitudes. A mixed-method would thus provide the best possible means to make things clear, and complete and provide a reputable understanding of the complexity of this topic (Manjengwa, 2020). This sort of approach is very effective when participatory studies need to be conducted. A participatory approach is also necessary to truly understand the nuances, trends and existing barriers within aerospace engineering.

It must be understood that the mixed methods approach is intrinsically a bottom-up approach as the expected change that this study may bring is coming from the lowest level of the organisation. While no bottom-up approach can exist without the underlying consent from the higher authorities, it can be argued that the process of necessitating change is, in essence, decentralised. The multiple methods employed vary from participatory research (refer section 2.3), where the researcher is making changes to the already existing system, subjecting the participants to these changes and using this new scenario to obtain insights. The researcher is in close proximity with the subjects under study and makes the necessary changes to the study based on the intermediate results. Two methods of data collection are employed and this is elaborated in section 2.7. The overarching research methods can be summarised in Figure 2.1.

2.3. Action Research

This mixed (research) method approach involves a two-step procedure which constitutes the basic framework of Action Research. This form of research is fundamental to initiating change in institutions (in this case, the TU Delft Faculteit Luchtvaart- en Ruimtevaarttechniek (LR)). This will be the central research method used under the umbrella of mixed methods and it can be used as a powerful tool

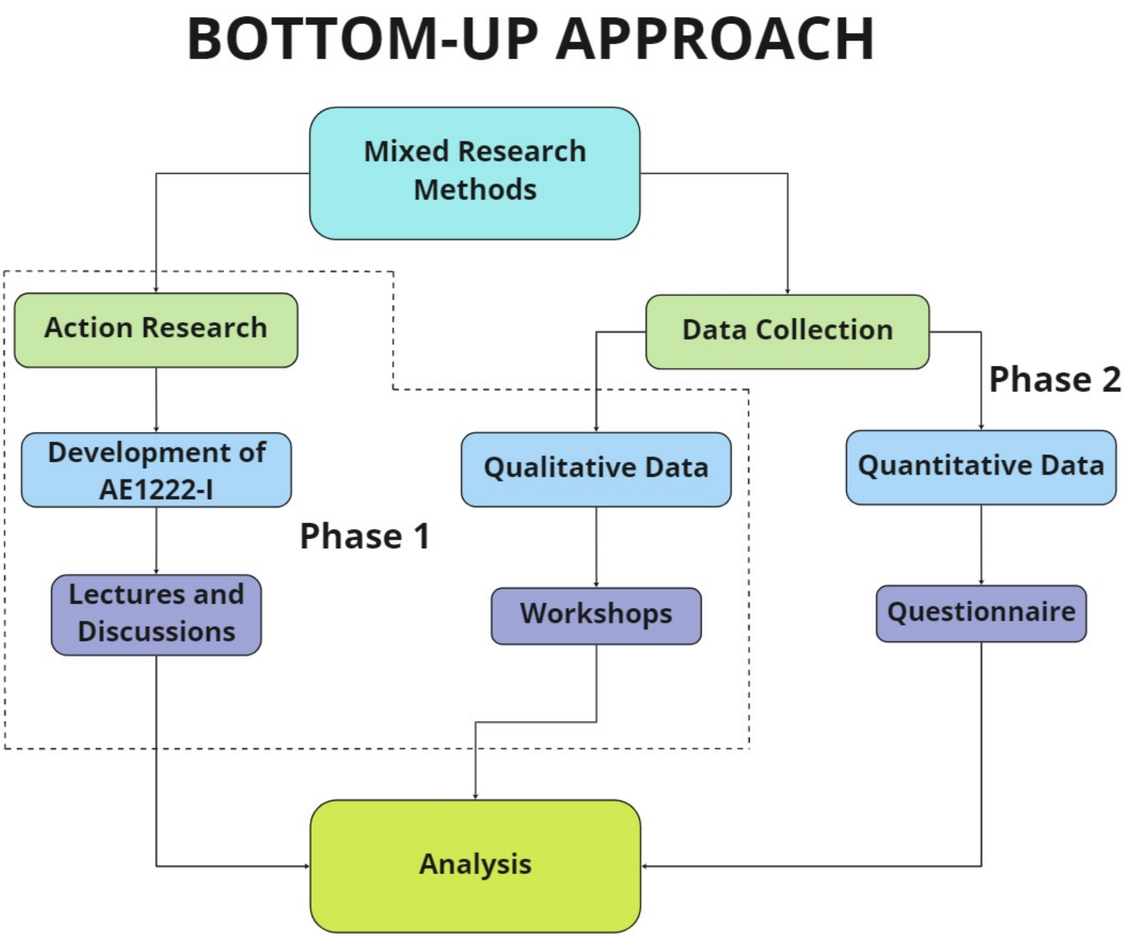


Figure 2.1: The mixed research method approach followed in this thesis is intrinsically a Bottom-Up approach

to link research and practice (Avison et al., 1999). This form of research is capable of synergistic-ally knitting together these two aspects which can help provide short-term solutions. This possibly gives aviation/aerospace a better class of engineers who can take on the challenges posed by climate change. Further, this mode of research requires certain creativity and skill which keeps the researcher focused and necessitates vivid expertise to successfully initiate change (McTaggart, 2002).

The two-step procedure mentioned above involves a very comprehensive process to ascertain that the research is a success. The first step or Phase 1 included identifying a suitable Aerospace Engineering course which could be adapted such that a new module would be introduced into the already existing curriculum. This adaption of the course required a very seamless and suitable transition which would not tamper with the existing learning goals of the course while ensuring that the sustainability aspect was not taken for granted by the students either. To find an appropriate course, my daily supervisor Prof. Michiel Schuurman suggested making these sustainability changes to his course which is given for 1st year Bachelor AE students. This is Course Code Project (AE1222-I) and is called Design and Construction [1]. An in-depth discussion about this course is provided in the section below. Phase 2 on the other hand involves successfully familiarizing the concepts of sustainability and circularity to the students. This goes hand in hand with encouraging them to use these approaches in their assignment and ensuring that they have a firm grasp on the fundamental aspect of aerospace engineering. Along with this participatory technique, qualitative and quantitative research methods are required to be employed to measure perceptions, change and the impact of the newly adapted course and participatory lectures. Here, the methods used are workshops, extensive discussions and a survey. This

[1]AE1222-I will be referred to as Design and Construction or AE1222-I interchangeably henceforth

two-phase Action research method and its sub-methods can be seen in Figure 2.1.

2.4. Bottom-up Approach

The basis of this thesis revolves around the bottom-up approach that most corporate firms are moving towards. Here, a small team (often called a Green Team) is formed by committed individuals who are part of the organisation and are committed to changing the way things are run in the organisation. This is usually specific to the environmental direction in which the company or organisation is headed. Secondly, these teams are granted certain independence by the higher-ups in the organisation. This ensures that they can work without being influenced by the larger structures which are less flexible, adaptable and historically locked into their conventional behavioural patterns (Bolghari and Hajimaghsoodi, 2017).

The bottom-up approach has been previously explored in the context of sustainability and it has clear-cut advantages in the quest to make an organisation in favour of an environmental disposition (Lingwood, 2021; Smith, 2008). Jans, 2021 argues that the success of a bottom-up approach is because it is instrumental in developing a pro-environmental social identity among people and this in turn provides the incentive for others to follow suit. This approach is also extremely advantageous as it opens up an enormous number of possibilities due to the depth of creative minds who are present at the bottom of the hierarchical chain in an organisation. In most cases, a Top-Down approach is very limited in its pathways to exploring lucrative methods to be sustainable. While the bottom-up approach has to constantly deal with the realm of uncertainty and concern, it is a means to perpetually preserve the idea of being pro-environmental. Also, it is for the benefit of the future of the aerospace community that this concept is embedded in the DNA of every engineer and this approach is hence a more effective means to do this. This Action research is purported to be for the benefit of young, aerospace engineers who are in their Bachelor's education. Hence, a top-down approach may also assume to take the form of an overarching set of rules or norms which may be too stringent for the students to comprehend, save, as a rule, or law (Asana, 2021). On the other hand, a bottom-up approach can and may inspire the stakeholders in education to consider incorporating a framework for making sustainability education a lot more emphasised in the regular curriculum (Source, 2021). The biggest factor in favour of the bottom-up approach is that it follows a participatory approach and involves ideas from the smallest of the stakeholders. This, in some way, takes away the authority of the scientific 'experts' and also gives the floor to the 'society' to incorporate best practices in the common fight to solve the issue at hand.

In the context of this study, there were close interactions between the researcher and a TU Delft Green Team to ensure that the bottom-up approach was followed. This proved to be very effective because the ideals and the principles which the two parties had been very similar and as the end goals were also to initiate a behavioural change, this partnership [2] was key to maintaining the authenticity of the bottom-up approach. The Green Team which was involved in this study was the AE Green Team of the Technische Universiteit Delft (TUD). This Green Team is instrumental in ensuring that the Faculty of Aerospace Engineering is up to date with the rest of the University Faculties in their journey towards a fully sustainable campus by 2030 (TU Delft, 2022). This Green Team is headed by Irene Fernandez Villegas, Associate Professor of Aircraft Structures and Materials (ASM) at the TUD LR (TU Delft LR, 2022a). As she also is the coordinator of the Circular Aviation Lab, this interaction with the Green Team was further bolstered and was fast-tracked to promote regular discussions with relevant people and students. This interaction with the Green Team was further solidified as one active board member of the Green Team was part of my research as a Teaching Assistant (TA) for AE1222-I. This is **Kiva Mc Sorley** and she was my point of contact with the AE Green Team, and being a TA, she made sure that my work was within the scope of what was expected of this course.

2.4.1. SWOT Analysis

The bottom-up approach comes with its advantages and disadvantages. Employing this sort of modus operandi can have multiple consequences which may affect the outcome of the results. To explore

[2] It must be noted that the researcher is not a part of the Green Team.

this fully, a Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis was carried out on the approach which ensured that the method was critically analysed to be utilised as a suitable approach. This analysis can be seen in Table 2.2

STRENGTHS	WEAKNESSES
1) Creativity and ability to pay attention to detail. 2) Non-hierarchical process aiding more informed changes in curriculum. 3) Frugal means to promote sustainability across any organisation.	1) Lack of high-level insights. 2) Slower process which will challenging when large groups of students are considered. 3) Requires continuous effort in order to successfully send the message across.
OPPORTUNITIES	**THREATS**
1) The behavioural change that can influence policy change. 2) Promoting interdisciplinary TA's who are passionate about sustainability. 3) Saves time for lecturer and prevents overflowing agendas.	1) Absence of course managers who are passionate about the topic. 2) Large work load within the course: temporal value. 3) Allocation of a single course which may address sustainability.

Figure 2.2: SWOT Analysis of the Bottom-Up Approach for promoting sustainability at the TU Delft

2.5. Stakeholder Analysis

The various stakeholders of this study will be discussed in this section. While the stakeholders of the writer's thesis are briefly discussed in the Introduction, this section is a generalised stakeholder analysis of every Aerospace Engineering course at LR. This stakeholder analysis has been carried out to ensure that all the interests are understood and this can be referred to by future researchers who are employing a bottom-up approach to aid in the sustainability/circularity transition. This is also conducted to ensure a Management of Technology (MoT) perspective in this thesis. The aim of this thesis revolves around the incorporation of change in attitudes and when such a change is required, it is useful to understand the various collaborators involved in the big picture. As each stakeholder's viewpoint and participation are necessary for the successful integration of sustainability, this section provides a brief analysis of the existing stakeholders who are involved in the improvement of aerospace education at the LR. This dissection most closely resembles a normative stakeholder analysis (Schilling, 2008) due to the ethical obligations that this thesis tries to solve. The biggest advantage of a stakeholder analysis is that it is not inhibited by time or effort (Ackermann et al., 2011). Additionally, it provides a very parsimonious look at the various entities who govern a process.

The stakeholders are as follows. Please note that these stakeholders may vary for other faculties at the TUD. This is specific to the Faculty of Aerospace Engineering (TU Delft LR, 2022b):

1. **Management Team:** This team is headed by the Dean, Prof Henri Werij who also acts as the chairman of this stakeholder group. This team also comprises the Department Heads of the various scientific departments. These are Prof.dr.ir. Leo Veldhuis - head of Flow Physics and

Technology (FPT) [3], Prof.dr.ir. Jacco Hoekstra - head of Control and Operation (CO), Prof.dr.ir. Rinze Benedictus - head of ASM and Prof.dr.ir. Pieter Visser - head of Space Engineering (SE). Additionally, this team also comprises the Director of Education, Ir. Joris Melkert. All these individuals are responsible for the content of education at the LR. They are focused on delivering world-class, aerospace education to the students while focusing on research and innovation at every level. This is in accordance with the Nederlands-Vlaamse Accreditatieorganisatie (NVAO)[4] and their direction and guidance seep down the system in every course and as a prerequisite, their expertise converges at maintaining the stature of the aerospace program as one of the best in the world. This has constantly reaped benefits like being in the top 5% of the best-performing universities in the **'QS Rankings of the Top Universities'** worldwide (TU Delft, 2021).

2. **Scientific Departments:** The departments mentioned above each have a strong team of associate professors, assistant professors, managers and support staff who are actively responsible for research projects, funding and quality education. The heads of these departments are the link to the management teams and they are also collectively responsible for ensuring that the curriculum of each course is in sync with the requirements of the accreditation board. However, this particular stakeholder group is capable of bringing about change in the structure of courses after careful consultation with the management team. However, the prime focus of this group revolves around keeping in touch with industry trends, innovation and cutting-edge technology. As education is an ever-evolving discipline, these departments must be up-to-date with the state-of-the-art so that the students can keep pace with the ever-evolving technical knowledge.

3. **Climate Action Task Force:** This is an advisory committee who are responsible for keeping the LR's activities in line with TUD's goal of being carbon neutral by 2030. This task force takes strides in ensuring that the concept of sustainability is embedded in education, research and also the day-to-day activities of the faculty. This task force is headed by Irene Fernandez Villegas, Associate Professor of Aerospace Structures and Materials at the LR. This task force is committed to making a change in people's mentality towards sustainability and this is facilitated by its members leading by example. They are, in principle, activists within the Faculty who aim to use this platform to raise awareness, create a pro-environmental identity and make significant changes to the way a Technical faculty like Aerospace Engineering can be run.

4. **AE Green Team:** This stakeholder group is a student-run organisation within the Faculty that specialize in the bottom-up approach which is going to be closely followed in this thesis. They were founded in 2019-2022 and this was part of a bigger drive across TUD to aid in expediting the realisation of climate goals by 2030. This team focuses on the incorporation of sustainability in education, organising social events which promote environmental behaviour and also will bring the advice of the Climate Action Task Force into existence. While the team is small, they are a committed group of AE students who take the pledge to explore opportunities where sustainability can permeate into the minds of all the members of the Faculty. They develop comprehensive reports [5] which can aid staff and researchers to adopt sustainability in their course design. All in all, they are the first movers in most sustainability-related activities at the Faculty and epitomize the bottom-up approach.

5. **Student Associations:** This is a relatively important stakeholder group who are involved in myriad activities at the Faculty and is responsible for the students. They comprise mainly the De Vliegtuigbouwkundige Studievereniging 'Leonardo da Vinci' (VSV) and other department-wide study associations. While their involvement in education is minimal, they are extremely important to obtain education-related feedback, improve the existing culture within the Faculty and organise a host of events which are both educational and casual. These associations, although not related

[3] formerly Aerodynamics, Wind Energy and Power & Propulsion (AWEP)
[4] Accreditation Organisation of the Netherlands and Flanders
[5] The presence of the Inventory Report (Arblaster et al., 2020) was of utmost importance for the author to pursue this thesis.

to pro-environmental behaviours, can be galvanised with the right formula and can prove to be extremely effective channels which can aid sustainability. As feedback from the students after each quarter is collected by these associations, they are indirect propounders in sustainability whose potential can be explored.

6. **Lecturers and Course Managers:** The most important stakeholder group is undoubtedly a large number of course managers and lecturers who are instrumental in teaching and doing the grass-root level work of imparting knowledge to the students. These individuals possess a lion's share in the promulgation of sustainability education as the discretion of the intricate details of various courses is left to them. Now, these minute technicalities are the building blocks of an interesting course and this can go a long way in imbibing values in the minds of students. The values which we refer to are the pro-environmental values and the dependency on lecturers to be environmentally motivated individuals remains a firm constriction in the path towards the advancement of aerospace education for the students. At the moment, certain course managers work in collaboration with the Green Team to develop their courses to be more sustainability-friendly.

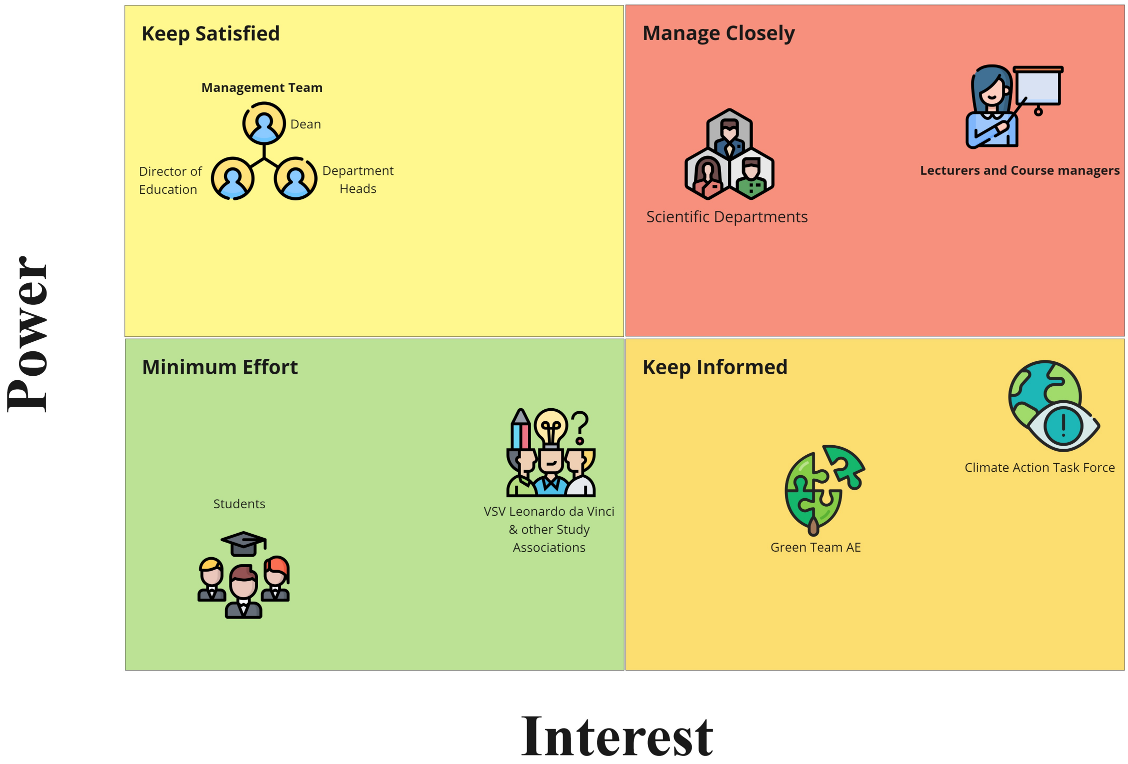
7. **Students:** This stakeholder group is the one who will be put to the test in this thesis. They are the future engineers of the aerospace world and are responsible for solving the problem of climate change and minimising the impact of aviation to achieve the climate goals which can mitigate global warming. They are unique in their position as they can influence what is being taught to them and this thesis will encompass their perceptions and attitudes after the incorporation of sustainability into a course which will be studied as a focus group.

2.5.1. Power-Interest Grid

In this section, the stakeholders mentioned above will be classified in a Power-Interest matrix so that their influence, passion and capacity to initiate a change in the curriculum of aerospace engineering can be visualised. This change in curriculum is specific to the aspect of sustainability as this is the concept being studied here. It must be noted that the stakeholders would vary, should the aspect being studied differ from sustainability. However, this classification of the power-interest matrix entails four different categories of stakeholders as inferred from the interview with Melkert, 2022. These are as follows:

1. **Low Power, Low Interest** These are the stakeholders who do not possess a lot of power to initiate change in the curriculum. In addition, they are not very interested in initiating these changes because of their interest in the Faculty of Aerospace. This group is represented by the students and the study associations (like the VSV) whose primary purpose is to obtain a world-class technical degree and to make the experience of students better respectively. These stakeholders need to be **monitored** occasionally as they can be stimulating players who can necessitate change at any moment in time. These stakeholders demand **minimum effort** in the big picture, however, they are important during instances of mass transition and if these stakeholders develop a notion of choosing sustainability, they can transition to a class which requires more effort to manage.

2. **Low Power, High Interest** This group encompasses the Climate Action Task Force and the GreenTeam AE. Their very existence is to aid in the sustainability transition and they are players who possess the expertise to make drastic changes, however, their influence over the proceedings is restricted to the role of activists. These stakeholders are required to **be kept informed** at all times so that they can capitalize on opportunities to incorporate sustainability in the Faculty. Additionally, these stakeholders are forced to employ bottom-up approaches due to their stronger influence to incite behavioural change rather than policy change. These dynamics are, however, changing in the Faculty and these stakeholders would be entrusted with larger roles in the coming years.



centering

Figure 2.3: Power-Interest Grid of the Stakeholders at the Faculty of Aerospace Engineering, TU Delft

3. **High Power, Low Interest** The Management Team at the LR is singly focused on delivering quality aerospace education. This group of stakeholders possess the highest power to initiate change in all realms, especially in sustainability. However, they are fixated on ensuring that the education provided is up to the high standards that TUD boasts of. While they have taken strong steps in the direction of sustainable aviation (via an Online Course on Sustainable Aviation TUD Online, 2021) and allocating the Green Team/Climate Action Task Force, it is not in their best interest to promote sustainability. This would come off as an additional burden to the students and staff alike and hence, they stick to achieving excellence in aerospace education. It is also of the belief that strong technical education can provide innovation potential that can solve climate change or drastically mitigate it. This stakeholder group should **be kept satisfied** and this should be done effectively so that they do not lose interest or miss the sustainability train.

4. **High Power, High Interest** This stakeholder group is the most important one and they are the ones who need to **be managed closely** given their influence on the situation of education as well as their interest in making things happen. While they do employ a bottom-up approach, their unique position as the administrators of their respective courses gives them the advantage to mould and nurture the minds of students in such a way that they can appreciate sustainability and pro-environmental thoughts. The course managers and the various professors who are a part of the Scientific Departments are mostly interested in pointing out the environmental benefits of aerospace engineering and while this is not a guarantee for everyone, as a collective, they tend to advocate environmental education and pro-sustainable practices. This is also seen in their own lives as most teachers at the LR have looked at the possibilities of incorporating sustainability education in their own respective courses' curricula.

2.6. Development of AE1222-I

The action research procedure in the case of this thesis requires the adaptation of a particular course. The incorporation of a sustainability and circularity angle to this course would form the basis of the further research approaches which are to be carried out. To facilitate this requirement, a bachelor-level course was chosen so that this pilot study could be effectively carried out. The reason for choosing a bachelor-level course is primarily to begin at the lowest level and observe if there can be some useful insights that can be derived from the study. Hence, the course chosen was AE1222-I and the course manager is Ir. Michiel Schuurman [6]. This is a course which is taken by 1st-year bachelor aerospace engineering students and they are required to design a portion of an aircraft.

In the course, groups of approximately 8-10 students are made to work together in a team simulating a structural design team. The course is run over two quarters or one semester and is split into three main assignments. The first project assignment focuses on a structural element of a rocker-bogie to be used for a planetary rover vehicle. In this part of the course, the students examine the properties of various materials associated with aircraft design and have the students give a preliminary design. In the second project assignment, the students must design a structure that will ultimately be tested by certain design variables. The design is for a compression panel used in a launcher vehicle. Some constraints are pre-set for the students, including the dimensions of the structure and the load it should be capable of sustaining while minimizing the structural weight. The third project assignment sees the students design a horizontal stabilizer for an aircraft/sailplane, this section consists of using the knowledge gained in the first and second assignments to answer a new structural-based design problem with more variables.

2.6.1. Bloom's Taxonomy

As sustainability needed to be adapted to this already-existing course, it was decided that Bloom's taxonomy could be followed so that the academic relevance of the newly added portions would not be compromised. Bloom's Taxonomy is a pedagogical framework that aids educator's all over the world to develop learning goals or objectives which are classified into three broad areas, namely cognitive, affective (emotion-based) and psychomotor (action-based) domains. This framework is hierarchical and was devised by Benjamin Bloom in 1956 (Conklin, 2005). A revised taxonomy was developed in the year 2001, which will be the taxonomy followed in this thesis. The revised taxonomy is focused on six action words which perfectly capture the essence of educational objectives. These were followed in the process of development of the course to fit a sustainability module. How this was carried out is presented below and they are as follows:

1. **Remember** To ensure the Sustainability module was able to address this aspect of the taxonomy, the students were prepared to recognise the impending need to think sustainably. This included the need to remember the overall scope of the project as required by the course and recall the need for quantifying their environmental impact. This aspect is also given light when the students were asked to identify the appropriate Sustainability Development Goals (SDGS) which were related to their work. They were also expected to remember the 9Rs and incorporate them creatively and this in turn would serve as a means to inscribe the need for sustainability in their daily career-life.

2. **Understand** This portion of the taxonomy was given a lot of importance as the biggest issue plaguing society is the lack of empathetic engineers. Hence, the module required the students to decipher the underlying problem of design and manufacturing, illustrate its sources and classify the various sources of emissions which were present. The student groups were also advised to summarize their design choices and infer from the literature, the various pathways which they needed to consider for their design choices. Additionally, they were asked to compare these different pathways and justify their choices keeping sustainability in mind.

[6]Ir. Michiel Schuurman is also the supervisor of this thesis

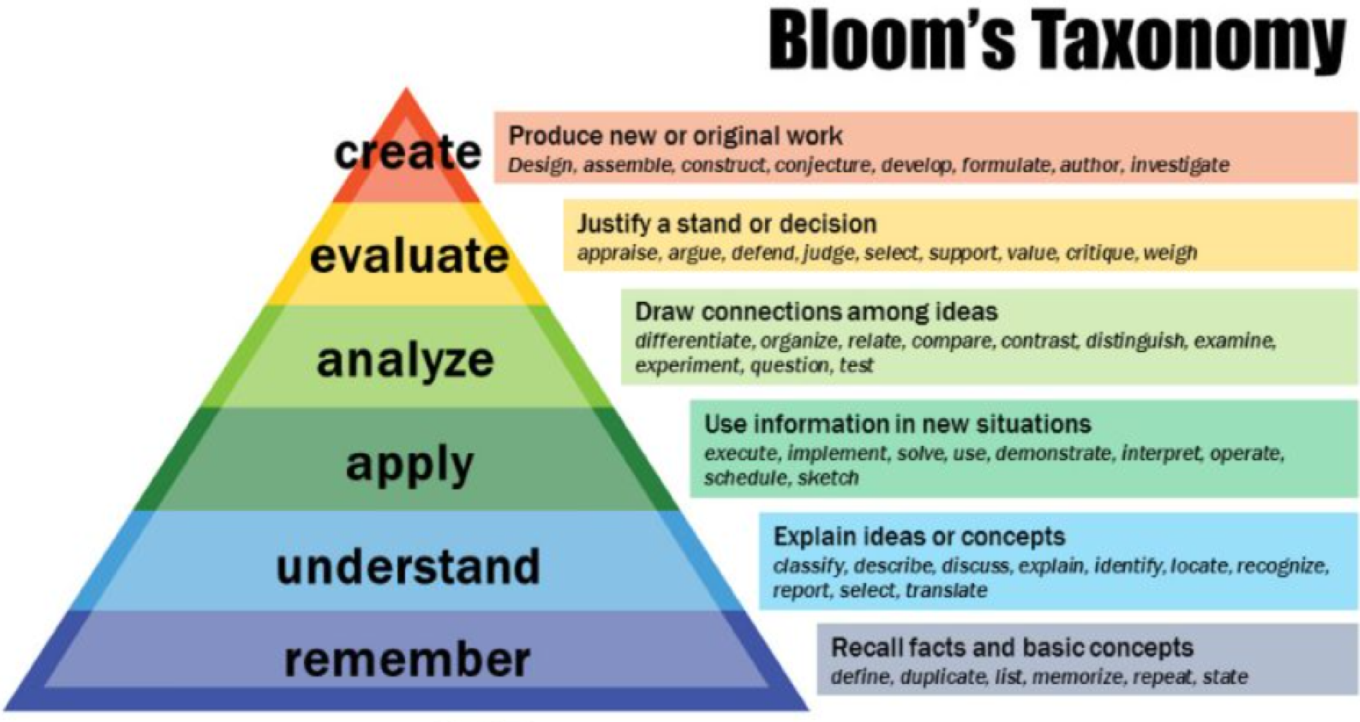


Figure 2.4: Bloom's Revised Taxonomy: Vanderbilt University Centre for Teaching (Armstrong, 2010)

3. **Apply** The beauty of AE1222-I is that it is a hands-on course. This automatically means that the quantification and choice selection of the student teams would be put to the test as they are required to execute their design and implement the manufacturing plan. Hence, it was easier to incorporate sustainability into this course as this would mean that hard work carried out by the students would be put to the test and as they would have to do it themselves, it would lead to a very practical-oriented approach which can aid in transferring attitudes.

4. **Analyze** The students were also invited to look into various aspects of the environmental impact such as noise, water and other non-carbon dioxide effects. This would in turn require differentiating approaches to address each effect. Hence, the groups were expected to organise their expertise and scrutinize the low-hanging fruit so that they could produce a comprehensive analysis of their team's environmental footprint. They had to trace each pathway back to the root to fully consider the life cycle of their design.

5. **Evaluate** The wing-box design required to be tested as part of the original AE1222-I course and this aspect is critical to aerospace engineers. It is not sustainable to develop an aircraft which is environmentally friendly by neglecting the fundamental aspect of airworthiness. Hence, the horizontal sections of all the student groups were tested and critiqued by the course management and success in the course was only guaranteed if it successfully passed all the criteria of testing and the design constraints which were fundamental to an aerospace course.

6. **Create** This aspect of the taxonomy is accounted for in the portion of circularity in addition to the overall manufacturing of the wing box. Students need to come up with ideas and execute them so that they can be considered a circular firm that gives focus to efficient design with reduced waste. Creating the wing box from a design of their own doing and planning the various aspects of time, budget and means etc. adds value to the creation and following a production plan is the first step to being able to mass produce the design. As the setting provided was very creative in

itself, the addition of parts was extremely easy to carry out.

The AE1222-I course is a very interesting 5 European Credit Transfer and Accumulation System (ECTS) course as it forms the basis of a design project. It is focused on a very real-life scenario in which most aerospace Original Equipment Manufacturer (OEM)'s could find themselves. Hence, the pragmatic setting of this course is very suitable for this research. The first portion of the course is structured to make students understand the properties of materials, write a production plan (which is manufactured by the TA) and take a course on Technical Writing. This first part is very extensive and introduces the students to a lot of information as they need to utilise this information to design and manufacture a wing spar in the second part. The study goals for this course are as follows (M. Schuurman, 2022):

- Complete an AE (sub)system's whole design cycle on your own.
- Executing a challenging team project while receiving outside direction and evaluating the results
- Compose an impactful design report.

The AE subsystem mentioned here is the wing spar which is a major load-carrying member of an aircraft wing. It usually runs along the span of the wing and is attached perpendicular to the fuselage. Like any aerospace project, this one also has design constraints which need to be met and the various concepts and principles learnt have to be implemented to come together as a wing spar. In short the students, in their respective design teams, are required to design a wing spar with certain constraining factors and do so by creating a production plan and executing it.

It must be noted that this course is an example of immense creativity from the course manager. The reader for this course is atypical of those of contemporary courses because of the relative ingenuity in the project description. The reader introduces a fictional company (who the students are a part of) and a similar client who requires the expertise of the student teams for designing and constructing a wing spar. The teams are provided with advisors (who constitute the TA team) and they help each student team through the course of the project. The wing spar is an important aircraft sub-system which the client requires for fitting into their novel sailplane and this contract is awarded to the students. This setting provided a very interesting setting where the author could use the current events of the world, namely COP26, and the pressure it has put on governments, businesses and the like. Hence, the fictional company requires the design team to also consider sustainability in its design. This is carried out by making sure that the design team chooses its design by taking into account the pathway which produces the least emissions. The design team is given the choice of manufacturing options. One is to execute the manufacturing manually (by machine) and the other option is to use a **KUKA robot** (which is automated). Additionally, to introduce a circularity aspect to the course, the design team is also required to follow the 9Rs of circularity and use hand tools for construction. As any manufacturing process is bound to waste material, this provided a perfect opportunity to introduce circularity to the course.

In short, The student team was supposed to quantify their carbon emissions based on the chosen pathway for manufacturing and also take into account the carbon emissions from the sourcing of the material and its transport. All these emissions were to be calculated using the given information and also by taking literature-based estimates. In a way, they were required to carry out a crude Life-Cycle Analysis (LCA) before they were allowed to manufacture their design. Additionally, they were to find novel uses for the material they wasted and choose the lower levels of the 9Rs of circularity to reduce the impact of their design. They were allowed to find circular solutions by invoking their creative inventiveness so that their potential as sustainable engineers could be explored. This also provided a breeding ground for ideas where the active and resourceful cognition of the students was tested. This was also added to ensure a compelling drive was present in this sustainability module that was developed for this course.

2.7. Data Collection

To aid in the understanding of perceptions and attitudes of students who took this course, it is imperative to follow a suitable method of data collection. This study employed both qualitative and quantitative data to ensure that the insights drawn are essentially unbiased, equitable and neutral in their recognition by the researcher. This two-step approach entails contrasting data which is further elaborated below. To simplify the data collection and the whole notion of action research, a small group of students was selected as a focus group. This group was headed by Kiva Mc Sorley, the TA who was also part of the AE Green Team and they numbered up to 21 students across two groups (E01E and E01F). These students were randomly selected from a class of around 400 students and they were, in essence, the target audience of the researcher.

2.7.1. Qualitative Data

The focal point of the quantitative data was the 21 students of the two aforementioned groups. They were subjected to three in-depth discussion sessions and this included their familiarization with fundamental sustainability concepts which are necessary for engineers. These sessions also discussed the challenges that most companies face in implementing them and the various bad practices which currently exist in the aerospace industry. Additionally, a behavioural change discussion was initiated which possibly provided critical discernment to the students and was a starting point for sustainable ideas and creative circular solutions which they could use in the course. However, the underlying qualitative data which was collected was in the form of three Workshops. Of these three, one workshop was instrumental in understanding the perceptions of the students toward sustainability and the impact of aviation's current situation on their future careers. The other two workshops provided deep discernment of their motivations, responsiveness and responsibility towards the environment. The outlines of the workshops are found in the Appendices B, E and F.

2.7.2. Quantitative Data

This portion of the data collection was based on a questionnaire which consisted of 81 items. The items were divided into six sections which were then sent out to the students via the official channel of Brightspace. After this, two reminders were also sent to the students via the internal communication channels of the students by the TA's. This questionnaire was sent out to the entire class of 400 students and this was carried out at the end of the course period during the Final Peer Evaluation period. The six sections were as follows:

1. Demographics and Career Goals
2. Interdisciplinary Education Perception Scale (IEPS)
3. Interdisciplinarity Skills
4. Climate Change Scepticism
5. Sustainability Effectiveness Scepticism
6. Environmental Responsibility

This list of sections is not an exhaustive list of obstacles or barriers, however, it was the most realistic choice as was perceived by the literature.

3

3. Literature Review

3.1. Sustainability in Universities

According to Kirchherr and Piscicelli, 2019, higher education professors are an important stakeholder group who are neglected when society is aiming for a sustainable transition. This is surprisingly poor (Kopnina, 2018) as the importance of education to bring about change in behaviours and lifestyle has constantly been highlighted. The good news is that sustainability has been incorporated into the education curriculum since the 1990s albeit with a different title: environmental education (Johnston, 2007).

Most times, when education on a certain topic starts at an early age, there is a huge scope to realise innovations and advancements in unimaginable ways. While starting early in an individual's education can help in making us realise more sustainable practices, it is important to understand that the scale of change in curriculum is immense and there is a huge need for change in all levels of education. Additionally, there is a need to live more frugal and this can translate to various sustainable innovations and lead to a cycle of using materials and reducing the negative impact on the earth. According to Klaniecki et al., 2018, behavioural change is an effective means to achieve sustainable development and it can be argued that these are very effective when a student is trained with it, instead of realising it later in life.

The available literature today is very clear in identifying the Universities which aid in a Sustainable transition. The general trends are all in favour of European Universities and a major portion of these universities are in the Netherlands, the United Kingdom and Sweden (Holmberg and Samuelsson, 2005). The Dutch government envisions a complete circular transition by 2050 in all sectors and this is evident in its university education manifesto as well (Ministerie van Infrastructuur en Waterstaat, 2021). With the help of the Ellen MacArthur Foundation, Delft University of Technology is at the forefront of raising awareness of the Circular Economy and its benefits (Ellen MacArthur Foundation, 2020). Several courses are also provided to help realise this goal. The Massive Open Online Course (MOOC) provided by TU Delft is a strong step in this direction (TUD Online, 2018). This MOOC, taught by Professor David Peck has had a total of 1700 participants from 49 countries (cf CE MOOC). Many Master's Programs in the Faculty of Industrial Design also aim at endorsing Circularity in education and help to aid students adopt a mentality of circularity in their curriculum.

The LDE Centre for Sustainability is also providing a host of around four Master Programs to propagate Circular thinking. To aid Master students from different disciplines, they also provide Minor programs that can help in specific case-wise understandings of circularity in engineering (LDE, 2022). As these are not a part of the Aerospace Engineering faculty's curriculum, it is hard to see a large portion of Aerospace students taking up these courses or minors. This is bound to change, however, and these obstacles will be studied through the employment of suitable research methods.

The University of Manchester and the University of Utrecht have employed in-depth Case studies in their Circularity courses and this is a gold mine of information for anyone who is pursuing this topic for their thesis. They highlight specific trends which their respective University professors' have identified when incorporating Circularity in their curriculum. These trends can be solid foundations to identify potential roadblocks when circularity is incorporated into aerospace engineering. Furthermore, as there studies are recent, they are suitable for further investigation (Sibbel, 2009; Het Groene Brein, 2021).

3.2. Focus on High Quality

In a study by (Jaeger and Upadhyay, 2020), the main barriers which exist in the industry towards circularity are the presence of strict quality standards which show no compromise on quality and the expensive nature of incorporating recycling and refurbishing practices. Furthermore, there have been time constraints in the concept of disassembly of products and there is an inherent lack of information and awareness in these practices.

The aerospace industry has always had very high standards of safety, quality, efficiency and performance. These are incorporated in the AS91XX family of standards which are very stringent in their requirements (NQA, 2010). This is because of the critical nature of aviation accidents and casualties. An aviation disaster can make or break an airline and they cause massive breaks in the supply chain. Due to this, the requirement of raw materials is also expected of very high standards. This is a possible barrier that exists within the engineering mindset.

Additionally, the aerospace industry is highly dependent on the certification authorities who lay down stringent requirements and make the whole process a long one. These are the Federal Aviation Administration (FAA), European Union Aviation Safety Agency (EASA) and similar authorities. They employ draconian measures and hence they spend a lot of time checking if an aircraft air-frame is up to governmental standards. This process is expensive and time-consuming and if OEMs get the process wrong, they will inadvertently fall into losses.

This means that the circular nature of aerospace End-Of-Life (EOL) products needs to find some other application in another sector or industry where they can close the loop in an effective and useful manner. This is mostly seen in today's world, however, the energy requirements to close the loop are high and they also attribute to a considerable portion of greenhouse gases which makes the manufacturing of new products cheaper and more energy efficient. However, there is potential to imbibe these practices to prevent the waste of materials and resources as new technologies are being developed.

3.3. The potential of the Aerospace Industry to adopt Circularity

It is a widely accepted fact that Aerospace engineering and its dependent sectors are not circular thereby making them a challenge to promoting sustainability and reducing environmental degradation. There is, however, a silver lining to this cloud which stresses the potential of the aerospace sector to become circular.

Several means can be identified to help this industry become circular. These methods can be directly linked to specific Circular Economy (CE) principles which make this perfectly suited for the transition. It must be understood that there are many conflicts in the process which is what prevents the smooth transition currently. These are where the potential for the education of young engineers can help because they are unaffected by the pressures of society, corporates and industry norms when they undertake their coursework.

The means are as follows: (See Figure 3.1)

3.3.1. Smarter Product Use & Manufacture

(based of Domone et al., 2021)

- **Refuse**: The fact that aviation is the elephant in the room concerning emissions, unsustainable travel and ecological degradation, we must ask ourselves if flying is indeed a requirement. Flight

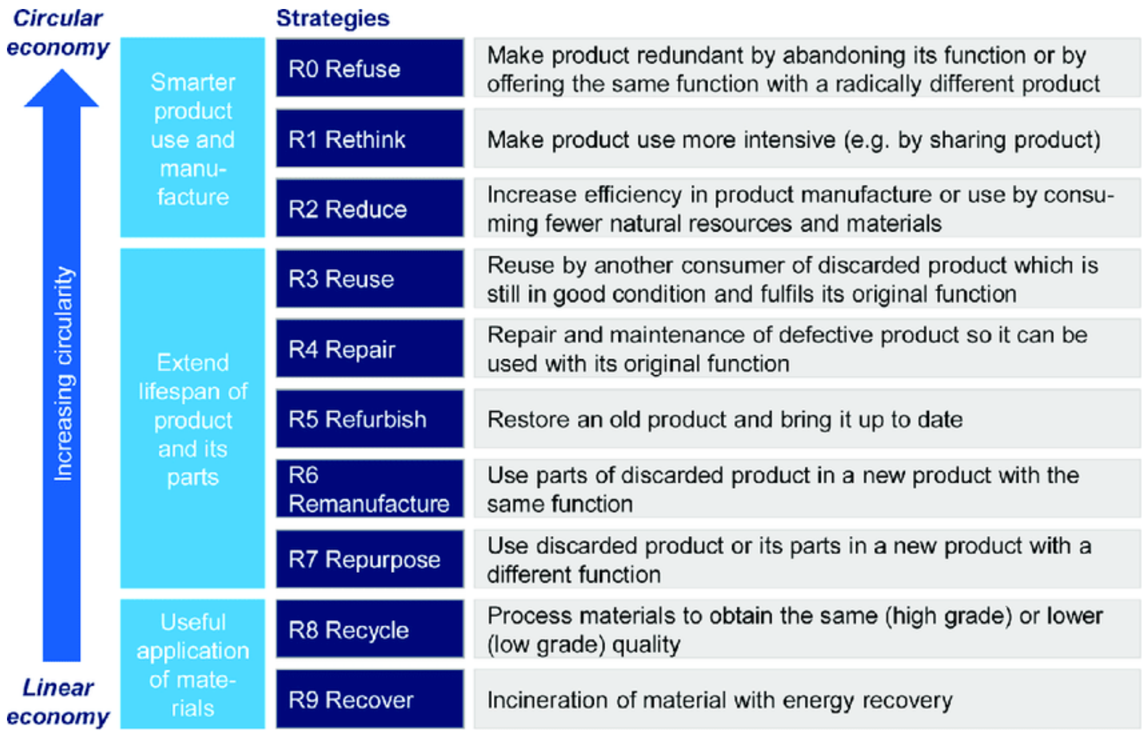


Figure 3.1: The 9R Framework in Circular Economy (Kirchherr and Piscicelli, 2019)

shaming has caused a lot of people to think of de-growth as a viable option to scale back operations and this is indeed very suitable for circularity and thereby sustainability (Stay Grounded, 2019).

- **Rethink**: This involves the use of aircraft to the maximum possible limit by incorporating low turnaround times and maintenance is a primary requirement for aircraft. This must apply to aircraft in all stages of its life and not just the 'first life'. Designers need to rethink their strategies for making this a reality. Design for disassembly, modular interiors, standard design and fewer dissimilar materials can help this cause.

- **Reduce waste and use recycled products**: Optimization of engineering manufacturing practices, use of automation and additive manufacturing can reduce the wastage of raw materials to a considerable extent. Recycling the waste material, like Aluminium, composites and plastics in other industries can help with this endeavour.

- **Reuse** Clever strategies can help reuse the parts of aircraft which undergo wear and tear. This can also be applied to aircraft as a whole. Additionally, the large number of aircraft which are restricted to aircraft bone-yards [1] can make a comeback for use considerably reducing the dependency on new materials.

- **Refurbish**: The faster the aircraft parts and sub-assemblies are repaired and refurbished, the longer they can be used. This also resets their fatigue life, which means they can be subject to their operating conditions for a longer time. This also increases life.

- **Re-manufacture**: This entails the reworking of components and parts into assemblies which are different from the original ones, but which perform the same function. This is a form of re-

[1] Aircraft Graveyards where scores of aeroplanes are stored to reuse if the need arises in the future (Lennane, 2020)

purposing components where they remain in the cycle and help maintain circularity. This also extends the EOL capabilities of individual components.

3.3.2. Expand on current Circular practices

(based of Meldrum, 2021)

- **Continued Airworthiness**: Aircraft are long-living technologies and they need to be operational for around 30 years. There is a solid policy to ensure they remain airworthy without causing safety hazards. This can be maximised by the aircraft OEMs ensuring that they carry out the required Maintenance, Repair and Overhaul (MRO) to the limit without a focus on profits and after-sales margins, but with an enhanced focus on safety and extending life.

- **Shift from 'Design for maintainability' to 'Design for Reuse'**: This involves the fundamental reasons for the manufacture of aircraft. If a certain technology is over-engineered by a certain margin, it can help to be used for a longer time without maintenance. This also increases the life of the product. This is a cultural aspect which exists within the industry. Engineering students, however, are immune to this mentality and they can be channelled to adopt the latter idea.

3.4. Interdisciplinary Education

The LDE Center for Sustainability has directed a majority of its analysis on ensuring interdisciplinary education and has set up the Interdisciplinary Thesis Labs to explore this aspect of sustainability. The nature of the complex problem that is climate change requires an in-depth analysis from multiple fields, each which is different from the other, but work towards a common goal Lam et al., 2014. It has been widely accepted by a host of researchers that the shortage of joint efforts and collaboration between different disciplines among higher education universities has always been a barrier to sustainability (Scarborough and Cantarello, 2018;Moore, 2005). Data access, effective communication and the resistance to change among various departments, faculties and organisations have plagued the development of sustainable-friendly universities for a while. This lack of coordination between various inter-educational units has slowed down pro-environmental attitudes among students and this sets a bad example to the students who are shaping their careers to emulate what is being taught to them. A decisive factor which causes problems in advancing sustainability in universities is the lack of researchers who can successfully incorporate social, environmental, financial and economic perspectives Velazquez et al., 2005. Hence, this also opens up a new set of opportunities for professionals who are subject matter experts in multiple domains, with a clear motivation toward pro-environmental ideas. Klaassen, 2018 and Gantogtokh and Quinlan, 2017 point out that the most favourable circumstance for learning takes place at the border of groups which are affiliated with contrasting research groups. This location creates a sort of 'third space' which is very effective to address the theme of sustainability, among others. As the environment and sustainability are very broad studies in themselves, it is only logical to find the sweet spot between various disciplines to make a difference in these domains.

A study on the positive effects of interdisciplinary teams has also hypothesised that the competence of world-renowned researchers in certain disciplines is not adequate when it comes to advancing environmental and social benefits. They were restrained when the focus of the research is a multi-faceted domain like the environment. Hence, decentralising the research groups and their communication was a recommendation which was to be followed (Capdevila et al., 2002). This research is being conducted on aerospace engineers and it would be deemed necessary to measure the perception of interdisciplinary studies among these students. Their interdisciplinary skills are also under the test when they are put to the text of a complex problem. These two aspects are hence used as measures which represent the perception of students of interdisciplinary education and their inherent skills which can be identified by making use of the scales of measurement as provided below.

3.4.1. Interdisciplinary Education Perception Scale

How engineers perceive different professionals belonging to other disciplines is a necessary facet which needs to be understood in areas where collaboration is key. While it is common knowledge that aerospace engineering is one of the most difficult and sought-after studies in the world, the individuals who take up this career would need to be empathetic and understanding of the educational background of other professionals as well (Vaughan et al., 2014). This scale is hence to be utilised to understand the impressions of future aerospace engineers on their peers in other disciplines. While the variance of the different disciplines is not specified, it can be understood that the main domains would be engineering, economics, politics and so on. As these are the main disciplines which are relevant to climate change, these would be briefly described in the survey.

This scale was originally developed for allied health professionals in 1990 and has been widely used in a very successful capacity. It consists of an 18-item questionnaire and it is based on a 6-point Likert Scale. The question items can be found in the Appendix.

3.4.2. Interdisciplinary Skills

The engineer who is purported to be high in interdisciplinary skills is usually said to be blessed with a set of specific traits. These traits can be measured by making use of the Interdisciplinary Skills measure and this has been researched by multiple studies. According to (Nikitina, 2006), the prime attribute that these individuals possess is the awareness of disciplinarity. While this seems like an inexhaustible experience, it must also be remembered that these individuals can recognise the limitations that come with multiple competencies. However, these individuals are effective communicators who can find a common ground with ease and make a universal surge to tackle complex issues (Newell et al., 2001).

This scale of measurement was developed by (Lisa R. Lattuca and Bergom, 2012) and it is based on a 5-point Likert Scale and consists of 8 survey items. This study was conducted in the United States of America and was subjected to the students of 31 different Universities and Colleges. This scale is studied for its validity and reliability and it passes off as extremely adequate to measure interdisciplinary competence. This scale will be used on the students and the items are seen in the Appendix.

3.5. Scepticism

There is an inherent questioning associated with climate change and the effectiveness of sustainable practices. Especially in a technical setting which puts aerospace engineering on a pedestal, it will be hard for students to truly understand the depth of their actions (Malik et al., 2019). As they are continuously dealing with polluting instruments and as they are uncertain about the immediate effects of climate change, it is easy to get into a routine of complacency when pro-environmental attitudes are concerned (Abd-Elwahed and Al-Bahi, 2020). While awareness is a good solution to solving this existing scepticism, it must be understood that this uncertainty can be found as a two-fold problem. These pathways are briefly explained below and each of these is explored with different scales. The measure of uncertainty is nice to be explored as a stand-alone concept and in juncture with scepticism (Buchko, 1994; Schauss and Sprenger, 2021).

3.5.1. Climate Change Scepticism

This is a growing concern in the Western world where there is a lot of apprehensions associated with anthropogenic climate change. While we live in a technological age where access to information is almost a basic human right, it can be accounted that there is a lot of mistrust in scientific claims due to political agendas, misinformation and overarching vested interests. The regard and support for scientific studies on the matter and their credibility are important drivers which affect public perception (Sarathchandra and Haltinner, 2021). Another driver that is identified among adults is their worldview and beliefs. Hence, Stevenson et al., 2014 suggests that education is an effective means to combat this cynicism. As the infusion of sustainability in education is key to overcoming this lingering cloud of doubt, (Malik et al., 2019) suggests that technical education is an important constituent of this change.

As climate change is often regarded as an ambiguous process, this uncertainty also is a breeding ground for Scepticism. This has detrimental impacts like the reduced desire to make a change among others (Maiorescu et al., 2020).

In this study, the work of Leal Filho et al., 2019 will be employed for measuring this aspect. It would be interesting to note that technical education students should inherently not be sceptic about climate change, however, it remains to be seen. This measure employs a 5-point Likert scale and consists of 14 items.

3.5.2. Environmental Effectiveness Scepticism

In today's world which is ever reliant on technology and energy use, being sustainable is more often an afterthought than an active concern. Aerospace Engineers are no different as they are responsible for designing aircraft and spacecraft which are tools for comfortable living at the expense of the environment. Hence, it is natural for engineers to genuinely question the effectiveness of sustainable practices in the industry. The process of educating engineers to be pro-environmental could be often perceived as a futile exercise which is done for the sake of some vested interest without any regard for the earth (Anderson and Kosnik, 2002). Another major driver for this kind of scepticism is the superficial intentions of claims made by pro-environmentalists who have a track record of being unsustainable (Bolderdijk et al., 2017). Most industries and governments today resort to 'greenwashing' practices which are confusing for the people and this also has negative effects on the war against climate change. Often, corporates and governments should refrain from these pro-environmental claims which play a part in increased ambiguity (Cho and Taylor, 2020).

Hence the work by Mohr et al., 1998 is used for understanding the scepticism levels among the students. This scale was developed for people's perception of marketing claims and contains 13 items each which employ a 7-point Likert Scale.

3.6. Environmental Responsibility

Creating the engineer of the future is a task which contains many facets to it. While the engineer is expected to be technically sound and critically aware of the intricacies involved in engineering, she/he must also be aware of the impact they leave behind. This effectively means that they need to be responsible for their actions and strive to reduce the negatives. To eliminate the negatives, they need to be realised firsthand Horvat and Voelker, 1976. Most engineers are tasked with this obligation only when they enter the industry. hence, the opportunity to ingrain this is lost. Hence, Horhota et al., 2014 argues that environmental responsibility is necessary for the sustainable development of the campus. Additionally, taking genuine responsibility for one's actions as an individual can help in doing the same as the collectives and countries Anderson and Kosnik, 2002. High environmental responsibility can help solve climate change at a faster pace. While offsets and technological schemes are often seen as incompetence, taking the blame and acting towards a goal is a powerful skill in an engineer's toolbox.

In this thesis, the researcher will employ the measure developed by Fernández-Manzanal et al., 2007 and this is a 20-item questionnaire which consists of a 5-point Likert Scale.

3.7. Conflict with Career Goals

The career path that a student takes is of utmost importance to the environment. In the realm of aerospace engineering, students may find themselves going into a non-compromising situation when it comes to the quality and performance of the products. Hence, the room for sustainability would be very and this can prove disastrous if every engineer is influenced by the existing agendas of the industry. As aircraft and spacecraft are extremely polluting technical marvels, the engineers who design and develop these should possess morals and ethics to make them 'free from sin'. While the AE industry seems at the crossroads of what is acceptable, it can be seen as a massive clean-up opportunity for drastic change. The career goals of the new crop of aerospace engineers need to be understood and they need to be competent to develop platforms which can cross out all the hard constraints that this demanding domain of engineering provides.

The adapted scale for measuring the career goals of the students is taken from Weigel et al., 2009 and it is a 4-point Likert scale consisting of 6 questions.

4

4. Results

This chapter discusses the comprehensive conclusions that can be drawn from this research. The results are divided into two sections as the research methods for each were contrasting. This includes a Quantitative portion and a Qualitative portion. While the methods are distinctive, there can be seen as an overarching theme which can be established from the results. Apart from the efficacious insights that are drawn, there is a consensus concerning certain measures and their correlations have been pin-pointed in this analysis. Care has been taken to ensure that these correlations are justified in both the quantitative and qualitative results.

4.1. Qualitative Data

This section is a concise take on the various observations which can be gathered from the proceedings of Workshop 1 (refer Appendix B). These results are classified under the various measures also discussed in Chapter 3 and the answers can be read in depth in the Appendix D. These results also contain the findings from Workshop 2 (refer Appendix E), Workshop 3 (refer Appendix F) and the other discussions which occurred with the students as and when was possible as part of the Action Research (refer section 2.3). It must be noted that this method was employed on only 21 students across two groups.

4.2. Career Goals

The biggest takeaway from the student's perspective on Career Goals is the strong, stoic standards they have subsumed for themselves. It is very clear to the students that their education in aerospace engineering is deeply set on the positive effects of technology. The biggest consensus in the student's minds is that they will live in a world where sustainable flying is the norm and not the exception. Most of the students are pretty well set on their future careers, while two of the students were not sure of their careers. Another common finding in the career dreams was that a large portion of the students chose to work in the Space Flight, Propulsion or Aerodynamics sectors. This was solidified by their intent to pursue a Master's education at TU Delft. The minority of the students chose Structures, Control & Simulation and Wind Energy as their preferred master track at TU Delft. This trend (of staying at TU Delft) was observed even in those students who did not know what they wanted to do after their bachelor's education. While these three major career paths are probably the most polluting when we look at the long run, most students expressed that their career choices would aid in realising the concept of sustainability. In addition, they also stated that they were committed to solving this issue as they would be possibly employed in an inherently polluting industry.

It must be noted that none of the students has any intention of giving up their dreams due to the negative impacts, which speaks volumes about their dedication. This can be summarized with this response '*I believe there is no point going against progress or change such as the growth of the aviation sector thus one can only try to make positive impacts on future developments.*' Additionally, there is accord in the student's responses concerning working toward the issue rather than slowing down the growth of aviation. This is seen as a challenge and a large portion of the group said that the aspect of sustainability in aerospace, can be considered as an additional design constraint which requires focus. Another student had this to say '*Aerospace engineering, as with engineering in general, is all about optimizing design, including its level of sustainability.*'

When posed with the question of conflict between their career goals and sustainability, the students saw this as an opportunity rather than a concern. In the eyes of budding aerospace engineers, optimism is generally high and they are confident in their abilities to make a positive impact due to the criticality of their training. This can be seen here '*Aerospace engineers have a critical way of thinking because you operate in extreme conditions.*'. Some students are already familiar with the extent to which they would work on sustainable aviation, along the lines of electrification and hydrogen propulsion. '*I am interested in designing hybrid or fully electrical planes, in the hope to make flight sustainable.*' Others are assured that while the harm caused by aviation is undoubtedly a cause of concern, there are a host of exceptional elements which make aviation a big boon to the world. Hence, their careers need to focus on cleaning up the impact of aviation. '*Since aviation will exist anyhow it is best to try and work in the field to make it more sustainable.*'

All these responses can be found in Appendix D and the underlying message of the majority was a very clear goal of working towards sustainable aviation, keeping in mind that technology can solve the problems it has caused by the sheer dedication, hope and faith in an engineering attitude which will not rest until the problem has been solved.

4.3. Interdisciplinarity

The basis of sustainability appearing in all aerospace courses was the main question posed in this section. To this, the majority of the students admitted that a single course on sustainability would do no good to the overall picture. This is because the essence of the theme is then lost very quickly and becomes counter-productive as students would possibly look at the aspect of sustainability as merely an obstruction in their journey toward an aerospace diploma. '*I think one course about this subject would be boring and students would quickly lose interest, maybe even making the course counterproductive. I think if it is a small part of (almost) all courses, the professors can very specifically explain how sustainability can be improved for their course subject and it will be more interesting for the student and more effective against climate change.'*. Another finding is the urgency of the problem of climate change. This is a motivating factor for most students as they believe the pressing need for sustainability needs to be transmitted to students as a recurring message. This would in fact aid brighter minds to bring about change. This student brings this fact to light: *'I don't know to what extent the urgency of the problem is being transferred to students if they only have one topic about it. Rather, continuous education should be taught of it, if it is such a big problem.'*

The topic of interdisciplinary learning being introduced to engineering courses had a variety of responses. Some students were all in for the idea of this being a regular part of their curriculum. Others, on the other hand, were slightly more unconvinced as this would take the importance away from their bachelor's being an Aerospace engineering course. The introduction of politics, economics, and social sciences would undoubtedly have a positive effect on sustainability as these aspects govern this concept in today's world. However, this idea would complicate students' education (especially at the bachelor's level). *'I don't think it's something an engineer necessarily needs to know, since they don't make those decisions but it could be something that could be offered as an elective. For those that do want to combine them.*' Another interesting observation was that interdisciplinary education should be introduced to the other side of the technical spectrum as well. This is to aid in better understanding, communication and resolving impediments that may exist in a complex problem. This excerpt is very interesting to observe and speaks volumes: '*I think these need to be taught both ways. Engineers should be taught how politicians think etc., however, the politicians should be also taught about how engineering solutions work, as many people (not necessarily the politicians) do not know how the technology can help improve sustainability.*'

4.4. Environmental Responsibility

This measure was one of the workshop sections which was met with the most introspective responses. The general agreement with the students was that they were all responsible for climate change as their inherent lifestyles, activities and behavioural patterns were all contributors to climate change. These admissions, however, have many layers of meaning to them simply because some students immediate retract their responsibility with the fact that everyone is also responsible for the same issue. *'I do consider myself more responsible than most, because I am a pilot. But I do not believe that a solution can be found by working alone.'* Some students, on the other hand, were accepting of their contribution and believe that they can raise awareness, take behavioural steps and set an example in their personal lives so that others can follow suit. This can be seen here: *'I believe that as a privileged individual who has choices and options in everyday life such as travel, food choices etc... I am responsible for making greener choices and trying to limit my impact.'*

When confronted with the idea of being responsible for possibly working in an industry which is polluting, the students were all accepting of this prospect. However, the perception of their technical competence was, in fact, overpowering and this competence was what they rely on to absolve their industries' past mistakes. This can be summarised here: '*The industry I plan to work in is currently largely responsible for polluting the atmosphere. While I may not be responsible for contributing to its pollution, I may become responsible if the industry does not improve itself in the factor of sustainability.*' Alternate solutions were already taking effect in the minds of a few students '*Yes and I think if you are working in such an industry you should take the pollution into account and think of a way to reduce it or if it is not possible you need to pay extra for the pollution*'.

Finally, the whole focus group was in accord with the fact that human beings and industries are all collectively responsible for climate change.'*Yes. It is impossible to pin this responsibility on one individual. We all affect the Earth as we live, and must all take responsibility.*' This also opened up the discussion for taking collective measures which can benefit the environment which is rooted in understanding various perspectives. Another observation was that the levels of responsibility vary from individual to organisation, however, the obligation to do something good, irrespective of the outcome, is to be shared by everyone. '*One is even more responsible if they do not try to reduce their contribution.*'

All in all, there is a common theme of being individually responsible as well as collectively responsible. However, the solution to this wicked problem requires a collective, holistic approach which cannot be carried out by an individual. That being said, the initiative can always start with an individual. Everyday, mundane things like energy consumption, transport, lifestyle habits etc., can also help to curtail climate change and everyone needs to do something to make a significant change.

4.5. Temporal and Academic Value

The aerospace engineering course is an extremely rigorous course which barely provides any free time for the students. In such a tight time frame, it is a challenge to incorporate sustainability into the curriculum as it has a very small academic value [1]. Hence the students were quite consistent in mentioning that they would require additional sustainability modules in their courses, however, it would be of solid utility mostly in the design courses. This is because the introduction of sustainability in a course which is purely mathematical or physics-based would unnecessarily burden students with additional work. This would ultimately render useless the concept of sustainability. Also, topics like circularity can only take effect if it is being put into practice, imbibing environmental values and attitudes. '*Depends on the course, for a physics or coding course the sustainability aspect is not important enough to add to an already busy course, but for a design course, I find it important enough to get graded on that aspect too and then of course also make time for it during the course.*'

[1]when we consider grades, ECTS and the temporal distribution of these aspects

Another proposition which was discussed was the hypocritical nature of the sustainability being taught to aerospace engineers. This was treated with uproar as all the students were dead against this being insincere or self-righteous. The unison among the students was that education is necessary to make a change in perceived notions of their aerospace education. They require the sustainability aspect in their education to improve the grim picture that aviation currently possesses. This is also required for their self-awareness as human beings and that their actions as engineers can only result in doing good for the planet if they can understand the problem that plagues their career path. '*Teaching students about sustainability will change aircraft from being of 'mass pollution' into efficient, Earth-friendly travelling options.*' Also, to reiterate: '*I don't think it is hypocritical, as it shows the desire of wanting to change things and improve the current situation.*'

4.6. Sustainability Scepticism

In this section, the biggest question posed was whether anthropogenic Climate Change is a real phenomenon and everyone was aware of the human interference towards radiative forcing and the heating up of global temperatures. The notion of climate change as a conspiracy theory was non-existent and this was a relief in itself. '*Studies repeatedly show the effects of climate change. I believe it is very real. Scepticism is not the same as ignorance.*'

The students were all very hopeful of solving the climate change problem if everyone put in their best efforts. This, however, was the problem as they were not confident of humanity coming together to put in their best efforts. A few students believe that we can easily attain our climate goals, irrespective of how stringent they are, but it is a question of wanting to make a change. They are aware of the dependency on crude oil and high-quality products and why these products, unsustainable as they are, are still in widespread use today. '*I think the world just isn't committed enough to meet the set goals, but there will be an improvement in the coming years*' Also, there is a sentiment of reducing the impact to a considerable degree from all areas of industry. This can in turn help aviation and aerospace continue to operate until the foreseeable future before we come up with cutting-edge techniques to eliminate pollution. *'If we manage to get the global pollution down to an acceptable level we can continue with aviation'* This also ties down to short-term solutions versus long terms solutions to climate change.

The precept that aviation is very efficient, fast and economical was presented to the students and this inspired a very interesting take on the demand for aviation '*If aviation continues "as usual" and would only increase in size due to exponential growth, the industry would quickly be one of the most polluting on the planet. Continuous efforts have to be taken to ensure that we meet the climate goals.*' This is because the global percentage of people who have taken a flight is very low and that number is bound to increase with economic growth and globalization. Ultimately, the absence of a single solution to climate change should not give aviation the license to carry on polluting the atmosphere, however, it should necessitate change by taking drastic short-term steps as well as long-term ones.

4.7. Uncertainty

The majority of the students are sure of the contribution of aviation to climate change, however, it is not certain how much is aviation's contribution (concerning the percentage). While this was a rhetorical question, it was more to understand if the impact of aviation and its materials is understood by the students. Additionally, the students are all propounders of technology to negate the issue of climate change. This was expected to be the majority of the responses as they are the future of the industry's innovation, adaptation and change inception. '*Innovation in technology can help slow down climate change by reducing carbon emissions through the use of alternative, "green" resources.*' A host of the students prefer hydrogen and battery-powered aircraft and they are committed to working towards these. '*We can do a lot by innovation. Many people say for example that it's impossible to fly electric, but we work in an industry that has always done impossible things(if you would go back in time and tell people we can fly in the future, they wouldn't believe you)*'.

With the growing percentage of aviation's contribution to climate change, the students were asked

Table 4.1: Interdisciplinarity and Scepticism Link

Measure	Question	S11	S13
Interdisciplinarity (M4)	**Do you think ONE course on sustainability/ the environment will be enough to imbibe the urgency of the problem? Or do you think every course needs to have a sustainability angle to it? Elaborate.**	R1	R1,R2
Scepticism (M5)	**Do you believe climate change is real? Is it being exaggerated by older people who have enjoyed the benefits of burning fossil fuels all through their life?**	R1	R1,R2,R3
Temporal & Academic Value (M6)	Is there too much coursework in the bachelor program to accommodate sustainability in each course?	R1	R1,R2,R3

if they should give up their dreams of pursuing a career in aerospace engineering. To this, they were all vocal about their career calling to be a light in the face of darkness. Every student from the focus group were constantly in favour of not giving up their dreams, in fact, they took this up as a challenge to make an impact in the right direction. The customary matter-of course was to use this opportunity as a springboard to achieving great heights in their individual careers. '*No, there is a lot of work in aviation to make it more climate proof and it will always be needed so you are obligated to make it better.*' The constrained mentality of engineers also showed out in a positive manner by taking climate change as a necessary check-box that needed to be ticked off. '*No you should never do that. Just change your dream in such a way that it takes climate change into account. It will just be another requirement on the list. Just like the other requirements, it has to be met.*'

4.8. Interdisciplinarity and Scepticism Link

In this section, we explore an association between the responses of two students (Student 11 and Student 13)[2] who were very similar in their uncommon opinions. This relates the measures of Interdisciplinary thinking, Scepticism and Academic/temporal value. The two students were consistent in their point of view with respect to having a single course on sustainability in their course. They shared the feeling of exploring the course in-depth so that the students wouldn't gloss over the topic and instead receive comprehensive understanding of the course. They also were identical in pointing out that human beings, even with their best efforts, would not be able to come close to solving the problem of anthropogenic climate change. They were, however, unfazed in their ethic of trying to make a difference, irrespective of the grim outcome that humanity will face. It must also be noted that these two students are also coherent in their belief that adding sustainability modules into multiple aerospace courses are extremely futile because of the high workload and hence, their intended value is lost. Additionally, the time constraints are also very high and this means that courses would become overwhelming, leading to an indifference in attitude due to the substantial workload that already exists in Aerospace Engineering. Their responses can be found in Table 4.1.

4.9. Uncertainty and Scepticism Link

This is a brief relationship which was found between the opinion of a student who was extremely sceptical in the ability of various stakeholders to come together and solve the problem of climate change. This is primarily because of vested interests, competency and inclination to make a considerable change. This student was also very hesitant to fully trust technology and innovation as instruments to help reduce the problem. This is because the student believes that this technology, in the hands of egocentric humans would cloud good judgement and distort their responsibility to solve the problem and in turn focus on their current state and neglect the future of the environment. This student also is aware of the

[2]refer Appendix D for all the responses. S = Student (numbered 1-21); R = Response (numbered 1-3)

Table 4.2: Uncertainty and Scepticism Link

Measure	Question	S9	S16
Uncertainty (M3)	**If climate change is indeed happening, how much is aviation responsible for it? Will any action through technology or innovation help slow down the problem?**	R1,R2,R3	R1,R2,R3
Scepticism (M5)	**Do you think even with our best efforts, we will not be able to meet our climate goals by the end of the century? Why? If one unique solution does not exist to climate change, should aviation continue as usual because it is a very efficient means of transport?**	R1,R2,R3	R2,R3

Table 4.3: Scepticism & Career Goals and Interdisciplinarity & Temporal/Academic Value Link

Measure	Question	S15	S20
Interdisciplinarity (M4)	**As engineers, we often forget that the world has other aspects which need to be addressed for our technology to thrive like economics, policy, politics and social sciences. Do you think these need to be taught to engineers?**	R1,R2	R1,R2
Temporal/Academic value (M6)	**Do you think teaching students about sustainability in aerospace engineering is hypo-critic? Is it a waste of time for future aerospace engineers who are working on tools of 'mass-pollution'?**	N/A	R1
Career Goals (M1)	Would your career choice conflict with sustainability goals because aviation is a big part of the emissions problem? If and if not, how can you solve them?	R1,R2,R3	R1,R3
Scepticism (M5)	If one unique solution does not exist for climate change, should aviation continue as usual because it is a very efficient means of transport.	R1,R2,R3	N/A

contributions of other sectors in their contribution to climate change and would rather use an integrated approach to solve the issues of all transport sectors. The student is also hopeful of striving toward their career dreams by keeping the environment at the back of their mind at all times. Refer Table 4.2 for the summary of the responses.

Another student's response that embodies uncertainty and scepticism is found in this excerpt. This student is confident that advanced technology can minimise climate change, however, this also comes with the growing demand for the best resources world over. This demand could set off another massive drive for resources and energy which will contribute to additional radiative forcing. Hence, this student is not very optimistic about the future. This student is also not willing to give up a possible career to protect the earth as this would mean someone else, who could possibly be less informed, would take the vacancy. This student is also confident that organisations and people with power are more responsible for climate change than anyone else as they possess the power to make a change. This is also seen in Table 4.2.

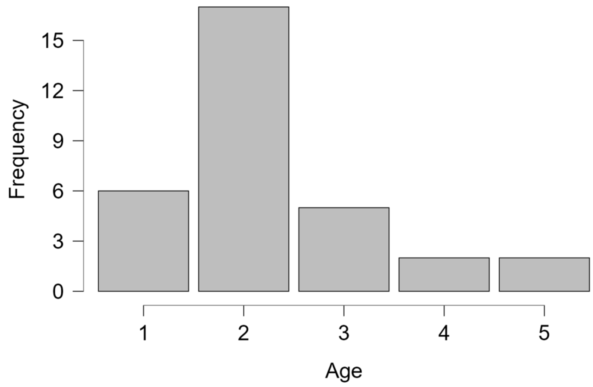


Figure 4.1: Age Distribution (N=32). 1 = 18 years; 2 = 19 years; 3 = 20 years; 4 = 21 years; 5 = 22 years

4.10. Scepticism and Career Goals link

This portion represents a very unique relation in the opinion of a student when asked about the continuation of aviation as usual. This student was hopeful that aviation would take a back foot in the years to come. This is because of the emergence of advanced virtual reality, computers and the shift of the world to an online workplace spurred by COVID-19. This is reinforced by the belief that climate change cannot be solved at an individual level and the people who are responsible for making big changes are constantly in opposition to each others views (namely the politicians). In order to work around this issue, the student proposes an identical bottom-up approach where aerospace engineers are capable of bringing sustainable innovation and policy into action. Hence, to achieve this, the student suggests reiterating environmental education at every opportunity possible. The student is also futuristic in their opinion regarding the state of the earth, should we be unable to avert the impending drastic effects of climate change. They point out, that, in the event of global warming crisis, aerospace engineering will be of very less demand as this domain would be of least priority to develop (refer Table 4.3). Hence, in order to continue pursuing a successful career in aerospace engineering, the student believes that sustainability education should be given high importance.

Table 4.4: Demographic characteristics

Demographics				**Number**	**Percentage (%)**
Gender	Male			25	78.13
	Female			7	21.87
	Prefer not to Say			0	0.00
	TOTAL			**32**	100
		M	**F**		
Age (in years)	18	6	0	6	18.75
	19	12	5	17	53.13
	20	4	1	5	15.63
	21	1	1	2	6.25
	22	2	0	2	6.25
	TOTAL	**25**	**7**	**32**	100

4.11. Interdisciplinarity and Temporal/Academic value link

This represents another unique association which was identified in the responses of a student who was asked if it was necessary to teach engineers the various aspects of the world such as economics, policy and social sciences. To this, the student responded saying that engineers were already familiar with these aspects. This was also solidified by the belief that engineering students need to be taught purely technical concepts which would maximise their effectiveness in society. Additionally, this student is also inherently aware of the responsibility they have and actively tries to reduce their impact as

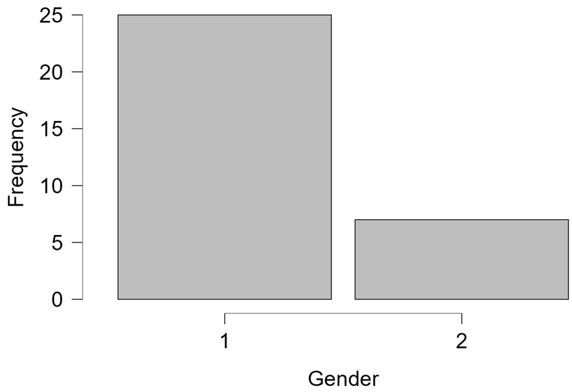


Figure 4.2: Gender Distribution (N=32). 1 = Male; 2 = Female; 3 = Prefer not to say

an individual, but this is purported to be in such a way that keeps sustainability to a bear minimum in their curriculum. Refer Table 4.3

Another interesting finding is that of a student who believes that sustainability is currently used as a buzz-word which aids in funding and conflicts with the aspect of finances. As being sustainable comes with an additional financial burden which may often be seen as an obstacle to practicing sustainability, this student believes that LR is currently under-developed as a sustainable Faculty. In addition, the student is not in favour of incorporating an interdisciplinary approach towards this aspect as this would aid in increased complexity. However, the solution to widespread climate change is, in the student's opinion, only possible through multiple pathways such as technology and policy. The biggest takeaway from this excerpt was that sustainability cannot be designated with a certain grade as this would mean trying too hard to force a concept which is already hanging by a thread. Refer Table 4.3

Table 4.5: Master Track Interests of the students (to be pursued at the TU Delft)

Master Interest	1st Choice	2nd Choice	3rd Choice	SUM	Percentage (1st choice in %)
Aerodynamics	11	0	0	11	34.38
Power and Propulsion	8	5	0	13	25.00
Space Flight	4	5	0	9	12.50
Control and Simulation	2	3	2	7	6.25
Aircraft Structures and Materials	4	2	0	6	12.50
Wind Energy	0	0	0	0	0.00
Flight Performance	0	1	0	1	0.00
Other	1	0	0	1	3.13
Not Sure	2	0	0	2	6.25
n=32					

Similar to the above student, another student believes that the introduction of sustainability-oriented courses would unnecessarily make students treat it as a hurdle which needs to be cleared and will not give enough importance to it. Also, to accommodate the sustainability-related modules, a portion of the existing curriculum would need to be given up or else it would compound the existing workload and be counter productive as AE is extremely busy as is. This student was also resourceful in pointing out that the demand for aviation would reduce, should the prices of flying go up. This is in line with the previous student's thoughts. Finally, the student agrees with incorporation of sustainability in every course as this is probably better than dedicating one single course which would be seen as a giveaway course which is easy to pass and score high grades.

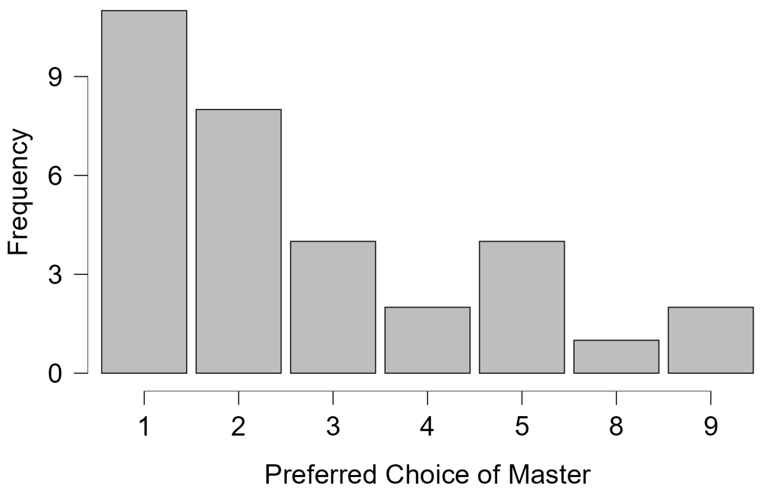


Figure 4.3: Preferred Master Track (n=32). 1 = Aerodynamics; 2 = Power and Propulsion; 3 = Space Flight; 4 = Control and Simulation; 5 = Aircraft Structures and Materials; 6 = Wind Energy; 7 = Flight Performance; 8 = Other; 9 = Not Sure

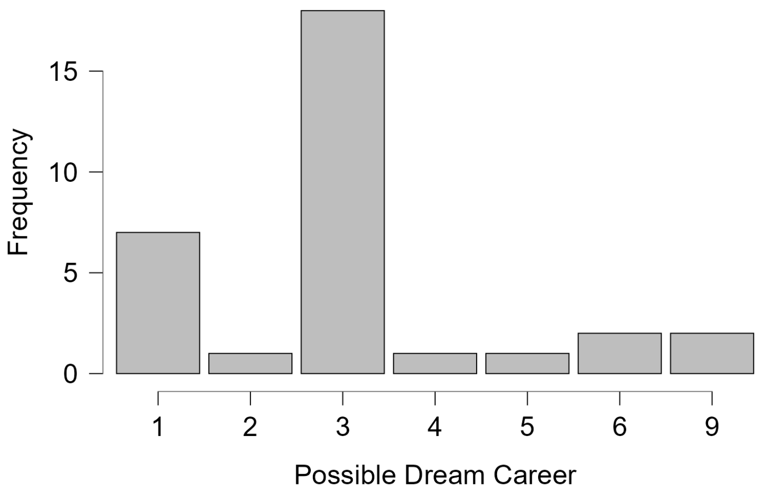


Figure 4.4: Possible Dream Career (n=32).1 = Flying; 2 = Air Traffic Control; 3 = Designing, building and maintaining aircraft and/or spacecraft; 4 = Military; 5 = Airlines/Airport; 6 = Space Programs; 7 = Academia; 8 = Other; 9 = Not sure

4.12. Quantitative Data

This section deals with the results from the questionnaire which was sent out to the students of AE1222-I and the responses also include those of the students of the focus group. The number of participants, age, AE1222-I group numbers, averages and other measures of central tendency and deviation are summarised in this section. The various measures computed are Interdisciplinary Education Perception Scale (IEPS), Interdisciplinary Skills, Environmental Responsibility, Climate Change Scepticism and Sustainability Effectiveness Scepticism. A reliability test is carried out and correlation between these measures are also computed. The individual measures are further explored in Appendix I.

4.12.1. Demographics and Career Goals

This questionnaire was completed by 32 respondents who all completed this course and it was ensured that the responses were collected after the completion of the course. Out of the respondents, 78.13% were male (n=25) and 21.87% were female (n=7). All the participants were within the age group between 18 and 22 which is expected for students who take up this bachelor course. The break up of the ages are shown in Table 4.4. A large portion of the students were 19 years old (53.13%). Out

Table 4.6: Preferred Dream Aerospace Career of the students

Dream Career	1st Choice	2nd Choice	3rd Choice	SUM	Percentage (only 1st choice in %)
Flying	7	0	0	7	21.88
Air Traffic Control	1	1	0	2	3.13
Designing, building and maintaining aircraft and/or spacecraft	18	5	1	24	56.25
Military	1	4	1	6	3.13
Airlines/Airport	1	0	4	5	3.13
Space Program	2	6	2	10	6.25
Academia	0	2	2	4	0.00
Other	0	0	2	2	0.00
Not Sure	2	2	2	6	6.25
n=32					

Table 4.7: Means and Standard Deviations of the Measures

	N	Missing	Mean	Std. Deviation	Range	Minimum	Maximum
Age	32	0	2.281	1.054	4.000	1.000	5.000
Gender	32	0	1.219	0.420	1.000	1.000	2.000
Environmental Responsibility	32	0	2.884	0.253	1.250	2.400	3.650
Effectiveness Scepticism	32	0	4.504	0.469	1.770	3.380	5.150
Climate Change Scepticism	32	0	4.147	0.445	1.790	3.140	4.930
Interdisciplinary Skills	32	0	3.956	0.548	2.250	2.750	5.000
Interdisciplinary Perception	32	0	4.548	0.455	1.610	3.780	5.390
Career Goals	32	0	2.573	0.244	1.170	2.000	3.170

of the 7 females who took the questionnaire, 5 were 19 years old as well. It must be noted that the Age is divided into 5 groups, namely 1 through 5, which represents the years 18, 19, 20, 21 and 22 respectively (refer Figure 4.1). This arrangement is also made for Gender, were, 1 represents Male and 2 represents Female. While 3 was meant for those who wished not to disclose their gender, there was no representation of this group (see Figure 4.2).

The preferred Master's tracks which the students wanted to pursue are listed in Table 4.5. It must be understood that the percentage is computed only for the Master track which was provided as a first preference. 34.38% of the group wanted to pursue Aerodynamics, 25% were interested in Propulsion and 12.5% set their sights on Space Flight and Aircraft Structures and materials each. While most students preferred Aerodynamics, it does not tell the whole story. It must be realised that the second and third choices of the students were inclined towards Space Flight and Propulsion. These three domains of Aerospace are possibly the most polluting of them all and hence the impact of these students in their respective domain would be massive, should they follow their choices (see Figure 4.3).

The tentative career options of the students were also explored. This data can be seen in the responses below (see Table 4.6). The bulk of the students were pursuing a career of designing aircraft/spacecraft, which was 56.25%. This was followed by those students who wanted to pursue a career in Flying commercial aircraft at 21.88%. The second and third choice options also place a considerable number of students in pursuing a career in Space and the Military (see Figure 4.4). These career options are undoubtedly the areas which contribute to climate change and hence the impact of these students will need to be immense if they are tasked with overhauling the entire system.

Table 4.8: Kaiser-Meyer-Olkin test

	MSA
Overall MSA	0.671
Environmental Responsibility	0.710
Effectiveness Scepticism	0.652
Climate Change Scepticism	0.655
Interdisciplinary Skills	0.700
Interdisciplinary Perception	0.651
Career Goals	0.674

Table 4.9: Bartlett's test

X^2	df	p
26.334	15.000	0.035

4.12.2. Descriptive Statistics

Table 4.7 shows the mean, range, minimum, maximum and and standard deviations of the different constructs. JASP 0.15.0.0 is the tool used in this thesis in order to carry out statistical analysis. This tool was developed by researchers at the University of Amsterdam and is an Open Source tool. The minimum score observed on Career Goals and was 2.00 and the maximum was 3.17 with a mean of 2.573 (SD=0.244). On the other hand, the minimum observed on Interdisciplinary Perception was 3.78 and the maximum was 5.39, with a mean of 4.548 (SD=0.455), which is relatively high. This trend was also seen in Effectiveness Scepticism with a minimum, maximum and mean (SD) of 3.38, 5.15 and 4.504 (0.469) respectively. Interdisciplinary Skills, provided a minimum value of 2.75 and a maximum of 5 with a mean of 3.956 (SD=0.548). Climate Change Scepticism possessed a minimum of 3.14 and a maximum of 4.93. It's mean and SD stood at 4.147 and 0.445 respectively. Finally, Environmental Responsibility scored 2.4, 3.650 and 2.884 (0.253) on minimum, maximum and mean (SD) correspondingly.

By making use of JASP, an exploratory factor analysis is carried out on the constructs. This is performed as there is no specific hypothesis that needs to be proved and to check the internal reliability of the constructs. Hence, a Kaiser-Meyer-Olkin (KMO) test and a Bartlett's test is carried out so as to check the construct validity. The KMO test gave a Measure of Sampling Adequacy (MSA) value of 0.671 overall, which is higher than the minimum required value of 0.5 (refer Table 4.8). All the individual MSA values are also consistently higher than 0.5. The Bartlett's test of sphericity result can be seen in the table and is is has a significance of 0.035 which makes it powerful. (see Table 4.9)

Table 4.10: Cronbach's Alpha of Constructs

	If item dropped		
Item	**Cronbach's α**	**Mean**	**SD**
Environmental Responsibility	0.551	2.884	0.253
Effectiveness Scepticism	0.643	4.026	0.469
Climate Change Scepticism	0.464	4.147	0.445
Interdisciplinary Skills	0.599	3.956	0.548
Interdisciplinary Perception	0.464	4.548	0.455
Career Goals	0.595	2.573	0.244

The Cronbach's Alpha is used in order to test the reliability of the measures. These values are seen in the Table. It can be observed that Climate Change Scepticism α = 0.464. This is relatively low.

Table 4.11: Cronbach's Alpha

Estimate	Cronbach's α	mean	sd
Point estimate	0.603	3.689	0.242
95% CI lower bound	0.340	3.605	0.194
95% CI upper bound	0.776	3.773	0.322

This is also observed in Interdisciplinary Perception α = 0.464 and Environmental Responsibility α = 0.551. A good reliable construct requires an $alpha$ value of at least 0.6 and this can be observed in Effectiveness Scepticism (α = 0.643). Interdisciplinary Skills and Career Goals have an alpha value of 0.599 and 0.595 accordingly. The overall Cronbach's alpha value is α = 0.603 a seen in the Table. This is acceptable, as it is closer to the 95% CI upper bound of 0.776. However, the individual constructs are not very reliable. It must be understood that since the reliability of these constructs are not higher than 0.7, these results must be critically interpreted and any further results may not be valid due to the low reliability. The reliability values can be seen in Table 4.11

A correlation analysis is also carried out in order to study the various interrelationships between the constructs. This can be seen in the Table. It is observed that Interdisciplinary Perception is moderately correlated with Climate Change Scepticism and this is a positive correlation. This is also highly significant (Spearman's rho = 0.548, r=<0.001). It is also seen that Interdisciplinary Skills moves positively with Environmental Responsibility, albeit moderately. This correlation is also quite significant (Spearman's rho = 0.423, r=0.008). The positive correlation with Environmental Responsibility is also shared by Climate Change Scepticism and Interdisciplinary Perception. These are weak correlations and they have a value of Spearman's rho = 0.392, r=0.013 and Spearman's rho = 0.325, r=0.035 respectively making them significant, but not highly significant. This data will be used to draw meaningful insights in the next chapter and this data can be seen in Table 4.12

Table 4.12: Spearman's Correlations

Variable		1	2	3	4	5	6	7	8
1. Age	Spearman's rho	–							
	p-value	–							
2. Gender	Spearman's rho	0.134	–						
	p-value	0.232	–						
3. Environmental Responsibility	Spearman's rho	0.076	0.243	–					
	p-value	0.340	0.090	–					
4. Effectiveness Scepticism	Spearman's rho	-0.033	-0.222	-0.060	–				
	p-value	0.571	0.889	0.628	–				
5. Climate Change Scepticism	Spearman's rho	0.014	0.041	**0.392***	-0.090	–			
	p-value	0.470	0.412	0.013	0.688	–			
6. Interdisciplinary Skills	Spearman's rho	0.294	0.218	**0.423****	0.016	0.147	–		
	p-value	0.051	0.115	0.008	0.466	0.212	–		
7. Interdisciplinary Perception	Spearman's rho	-0.288	0.254	**0.325***	-0.169	**0.548*****	0.168	–	
	p-value	0.945	0.080	0.035	0.822	< .001	0.179	–	
8. Career Goals	Spearman's rho	0.144	0.198	0.236	0.141	0.296	0.074	0.273	–
	p-value	0.216	0.139	0.097	0.221	0.050	0.344	0.066	–

4.13. Conclusion

This chapter presents the results from the various data collection methods used in this thesis. It must be noted that the reliability of the quantitative data is low and while this could be attributed to the low sample size, it must be critically considered while drawing correlations. The qualitative data is analysed for common and uncommon correlations and this draws some interesting insights. Environmental responsibility is a recurring measure which has high significance in both data collection methods. The quantitative correlations are also low-moderate due to the sample size and the low reliability. The implications of these results are discussed in the next chapter.

5
Discussion, Limitations, Recommendations and Scope for Future Work

5.1. Discussions

This chapter will provide a comprehensive analysis of the highlights of every part of the thesis until now. This includes the implications of the work, its relevance in today's education system and the practicality of its challenge it is carried out at the Bachelor level at the Faculty of Aerospace Engineering at the Delft University of Technology. There is a high-level priority given to making the TU Delft campus carbon neutral, sustainable and circular by 2030. In light of this, this study gives some understanding of the challenges and obstacles which need to be addressed to make TU Delft's climate goals a reality. This thesis topic was provided by the Leiden-Delft-Erasmus Universities (LDE) Center for Sustainability (CfS) in collaboration with the Royal Nationaal Lucht- en Ruimtevaartlaboratorium (NLR).

The LDE CfS is an organisation committed to making the Netherlands a sustainable society by taking necessary steps to aid the transition to a circular economy which could provide us with a fighting chance to become sustainable. Hence their research is mainly divided into 4 pillars namely, Circular Aviation, Sustainable Horticulture, Sustainable Hospitals and Circular Building Hub. They provide Master thesis topics for students of the three parent Universities [1] who are in their final year of graduation. The Circular Aviation hub has contributed to this thesis topic and the results of this thesis (and other theses from the lab) will be used for the betterment of the Aviation Industry. The connection to the industry is provided by the Royal NLR who is the case-holder for the results (and theses) of the lab.

When observing the work presented here, it can be automatically gauged that the thesis is to be used for the short and medium-term development of aerospace education. This will be used to instil sustainability in the future of the Aerospace and Aviation industry (aerospace students). This initiation of pro-environmental attitudes among students will aid in developing a mindset for sustainability in their daily lives as well. An additional possibility would be to help them critically think about circularity in every aspect of their future aerospace career. Hence, the first and foremost hurdle would be to provide an arena where the students are introduced to the concepts of sustainability and circularity early in their education. The secondary challenge would be to bolster this first step and reinforce the concepts learnt at every subsequent step throughout their educational career. However, if we look at the existing curriculum of aerospace engineers, they are taught to develop and design "machines of mass pollution". In addition, due to the criticality of flight, its stringent safety requirements and aerospace material standards, this industry is inflexible in its manufacturing procedures. The potential of using the circular design is huge, but it is a process which would require a substantial amount of effort for certification, transformation and adoption. The current aviation and aerospace industry is already too far down the

[1] Leiden University, Delft University of Technology and Erasmus University Rotterdam

path of ‘reliance on performance’ to be nudged into more sustainable practices. Hence, the bottom-up approach followed here is to create pro-environmental attitudes among students so that change comes from the grassroots.

It is a well-known fact that aerospace testing and certification take a considerable amount of time to be verified, evaluated and approved (Alderliesten et al., 2021). Once a design has passed its certification stage, this design is frozen because of the relative expense, extensive time frame and the disproportionate documentation and inconvenience associated with making changes. Additionally, aerospace designs are usually designed for more than three decades (30 years, if we consider the operational life of aircraft alone) and the manufacturing is carried out such that the design lasts for this extensive period. This leaves little to no room for making sustainable changes in their design like incorporating circularity. Hence aerospace engineers are locked into their conventional practices as these yield effective results which have greater chances for success. While the industry is not intrinsically unfavourable to being green, it is unenthusiastic to making drastic changes, which are the need of the hour.

To combat all these underlying issues and make a lasting change, this thesis topic is a gateway to explore options for the LDE, NLR and the AE Green Team to efficaciously make a change in the education of engineers from the bottom up. This has benefits which could transcend the attitudes of the current aerospace industry and possibly lead to drastic policy changes which are a great way to insinuate change. If the current crop of Aerospace engineers grows up in a world where sustainability is given more importance than, say, cost savings and faster travel, we can live in a world where flying can become green, efficient and egalitarian. While the aviation industry is plagued with other issues like fuel burn and expenses, there is a sense of urgency towards solving the issues of emissions and sourcing critical materials currently. However, these issues require long-term solutions which can only take effect in the next 10-20 years. In the meantime, every effort should be directed toward interdisciplinary education of sustainability in technical education so that we are ready and stand a chance to mitigate climate change.

This study, although may seem novel, is by no means unheard of at the TU Delft. The GreenTU has already carried out pilot studies at the Faculty of Civil Engineering and Geo-sciences, where Dr Daan Schraven was one of the participants of this pilot which is called the **Green Thread**. He worked in close collaboration with the GreenTU and was able to successfully incorporate sustainability in his course, similar to what Prof. Michiel Schuurman has done with AE1222-I. The effort to modify course material may seem like a big challenge, however, this can be easily overcome by hiring TAs to carry out this work. This is a frugal means of incorporating sustainability and it can be more effective than expected. As faculty members are moulding engineers of the future, it is their moral obligation to ensure that they are also well-versed with the intricacies of sustainability and circularity. This Green Thread can be an effective program which connects the various faculties of the TU Delft both environmentally and via interdisciplinary competence (TUD Education, 2022).

In technical education, sustainability often takes a back seat and rightfully so because of the consumption of resources, expending of energy and production of waste which are all directly or indirectly contributing to the destruction of nature and natural resources. While these are inherently not bad, it is the scale at which human beings have done this that makes it an issue. Hence, making use of a strong sustainability regime, would not be accepted by the general technical education system as this would lead to the decline of the purpose of technical education. However, a weak sustainability system can very well be adopted as this could have a snowballing effect which infiltrates the minds of engineers so much so that it can change their behavioural patterns, aiding the environment. This system, however, should not be left to an afterthought, but it needs to be actively embedded in technical education. To do this, following a set of learning goals can be of good use. Additionally, Bloom’s taxonomy is also a good measure to ensure that academic relevance is maintained in developing courses. This is imperative to keep the course in line with the various accreditation institutions like NVAO.

In the in-depth sessions, the researcher was careful to introduce the basic terminologies involved in aerospace sustainability. A brief list of topics covered is presented in the Appendix. These include 'green-washing', 'flight-shaming' and the current global trends which these terminologies are associated with. Fundamentally, the SDGS were at the core of most lessons given. While this thesis associates itself with SDG 4, as this means quality education for everyone, it must be noted that improving the existing picture of the SDGS also requires education and awareness, something which this thesis was very successful in relaying. The students were also asked to identify SDGS which they found relevant to their work in Design and Construction. To this, they provided the SDGs 12 and 13 as the most relevant (UNSD, 2022) [2].

Figure 5.1: Identified Sustainable Development Goals (SDGs)

The concept of war, military and their relation with the current political scene was also discussed as they are very relevant to sustainability. Since aerospace engineering finds large applications in the military, this seemed more relevant than ever. The concept of a LCA was also introduced to the students. The 9Rs of circularity were a recurring theme and interesting takes on these concepts were discussed and also observed in the reports submitted by the students. As this data is confidential, it is prohibited to share it in this study. Capturing the attention of the students was of utmost importance as this study is, more than a thesis, an opportunity to initiate change in young minds who can be easily influenced negatively. To assist in this, most interactions were backed up by videos and supportive games. The details of these can be found in the Appendices B, E and F. Most importantly, descriptive situations and students' perceptions of these aspects were other recurring concepts during the interactions. This was carried out to be up to date with the Learning Goals that are mentioned in the section.

In the extensive qualitative research that was conducted, the student's views on various obstacles which are agonizing the adoption of sustainability in aerospace engineering were studied. Relations and links between these obstacles were also explored and a comprehensive list of the student's responses can be seen in the appendix. The underlying obstacles are the conflict with Career Goals, Lack of Interdisciplinary Education, Environmental Responsibility, Scepticism, Uncertainty and Academic/Temporal Value associated. These aspects were studied employing a workshop and via other interactions and the findings are presented in the section.

Most students were adamant about sticking to their **career goals** and in fact, they have set strong

[2] Their assignment required them to calculate their carbon footprint of design and build; use the principles of 9R's of Circular Economy for their manufacturing

standards for their career which includes working a sustainable job and in a pro-environmental industry. Although most students wanted to work in Propulsion, Space or Aerodynamics, they would not change their goals because of the transgressions of the industry. While they understand that their career paths could be extremely unsustainable, they also believe that they can necessitate a change in their respective industries. They see this as a challenge which can be solved just like an engineering problem. The aspect of **lack of interdisciplinary education** in current aerospace education was taken with mixed feelings. However, a large perception was that interdisciplinary education was seen as a burden and an additional workload. Others on the other hand were all for the idea to be introduced in their curriculum on a broad level which can aid in communication and dialogue between disciplines in the real world. Almost all students were unconvinced about the idea of a single course on sustainability in their curriculum.

The question of **responsibility** of climate change produced interesting insights. Almost all students acknowledge the fact that they play a part in climate change. Additionally, they also maintain that industries and corporates are also responsible for their actions. The responsibility was reiterated by not taking a back seat and aiding climate change, but to collaborate with industries and making a change in this age-old problem. As almost all students believe in individual and collective responsibility, they immediately look for a solution as this is how technical minds usually work. This is also often used as an argument to free oneself of the responsibility thrust on them as they are engineers of the future. When presented with the query of the **academic and time value** of sustainability in courses, the students backed the critical importance of sustainability in their education. In short, they agreed that educational value was of high importance. However, the time aspect was met with some varied answers. While it is necessary to have modules, it would only make sense for design and hands-on courses. If it is for a theoretical course like Python Programming, it would be a waste of time and have no impact.

Scepticism of climate change and the effectiveness of sustainable practices towards realising a pro-environmentally friendly world were met with varied responses. All the students are firm believers that climate change is real and requires an immediate response. They are, however, mixed reactions when the effectiveness of our (humanity's) best efforts is concerned. While some students are optimistic that their effort will help realise sustainable and circular aviation, others are sceptical of the entire scenario. As global warming is a complex problem which has a big standing on the current politico-economic situation of various countries, they are pessimistic about solving the issue. Hence scepticism is more of the capability of all stakeholders coming together to make a change. The **uncertainty** of finding a solution to climate change was met with the optimism that technology brings with it. Most students are uncertain of the contribution of aviation to climate change, however, they are certain that path-breaking work would slow down aviation's impact. While it remains uncertain as to what defines 'path-breaking', the students propose multiple pathways that can help reduce the uncertainty associated with climate change. Uncertainty ultimately yields an opportunity to make things better as the negative effects are not yet realised (Wade, 2008).

There were interesting correlations in student responses which are summarised in the section. One such correlation is found among students who preferred a single course for sustainability in their curriculum. They were also more sceptic about effectively combating climate change and believed that we cannot mitigate the problem. They justify their stand in allocating a separate course, as every course has too much workload to incorporate an additional module currently. Another correlation was between students who were uncertain about the future of aerospace engineering and technology. These students were also quite sceptical about the effectiveness of sustainability in technical courses to make a change in the big picture. Pessimism ran high in the minds of these students as each technological advancement would be a driver for additional leeway to contribute to additional emissions.

An uncommon correlation was observed by a student who believed that the demand for aerospace and aviation would be negligible in the future. These trends are already taking shape in the aftermath of the pandemic and due to the congestion at Schipol Airport in the form of a new dawn of computers, online meetings and workspaces. This view is also related to extreme scepticism about the competence of top-down approaches in the face of opposing views, stakeholder conflicts and human greed. Another relation was identified in the perception of interdisciplinary education and academic value. The student perceives that engineers are aware of the goings-on of the world and need not be taught additional concepts that are multidisciplinary. The academic value of sustainability modules is hence not useful as technical education needs to take precedence.

The correlation between the above two constructs is also found elsewhere. A student is a sceptic about the effectiveness of sustainability as it is misused as a tool for financial gain or subsidy. The academic value is also lost when it is forced into the curriculum of technical education. This is a perfect example of scepticism and temporal value link. Also, the link with interdisciplinary education is observed as the student does not prefer added coursework due to its complexity. There was also a link between the effectiveness of our efforts being futile unless aviation is taxed more (an example of effectiveness scepticism) with the positive reception of more education on sustainability for most of the aerospace curriculum.

The quantitative data were collected from 32 students and the results are summarised in the section. The primary goal for this data was to form correlations between the studied measures. The measures are more or less similar to the qualitative study except for Temporal/Academic Value and Uncertainty as they were neglected in the study. These form barriers to sustainability in educational institutions (Maiorescu et al., 2020). The correlations observed with this data are more reliable as this has a statistical edge to it. The most significant correlation was found between Interdisciplinary Perception and Climate Change Scepticism. This was a positive correlation which does not indicate causality, but it simply means that these two constructs move together. Hence, those students who scored high on the Interdisciplinary Perception scale were also more inherently sceptic about the effect of climate change. Students who scored high on Interdisciplinary Skills were also more susceptible to being environmentally responsible individuals. Similarly, those students who scored high on Interdisciplinary Perception and Climate Change Scepticism were inherently more responsible towards the environment. While all the correlations are moderate, they are significant ones. The limitations of the quantitative study can be found in section 5.2.

5.1.1. Sustainability Dilemma

The consensus among most of the students was that Sustainability and its related topics were not given enough importance in education. Most students, in turn, demand a change in their curriculum as they understand the importance of being able to profess their careers in the future. This demand also stems from their responsibility toward climate change. As the younger generations want to see a measurable change in their world, they are dependent on the older generations who did not grow up with such a mentality. As sustainability slowly takes an increased role today, indifference is still rampant in the industry. Additionally, as most educators were not taught about the value of pro-environmental concepts (at least not with today's magnitude), it becomes harder for educators to provide for the student's appeal to have these concepts in their curriculum. The older generations tend to stick to the requirements in the Course Manual as this has provided for quality education for decades. Time and energy constraints also do not help the cause of the students. While this is by no means appropriating blame on any party, this conflict of interest raises a sustainability dilemma which we currently face.

There cannot be a single means to overcome this challenge. As this dilemma is prevalent in the industry, most aerospace students are subjected to archaic practices making education for sustainability counterproductive. The bottom-up approach proves to be a good means of countering this dilemma. While this approach proves extremely useful in the young community, it can also prove beneficial to imbibe pro-environmental attitudes among older generations. This can be done by spreading awareness of incentivised economic models like de-growth. It is common knowledge that exercising and staying fit leads to a healthy lifestyle which has benefits like fewer visits to the hospital. This incentivises leading an active lifestyle. If this active lifestyle can be achieved by reducing carbon emissions (for example, biking to work, taking the staircase, using public transport or reducing the consumption of processed food), people can save a lot of money and remain healthy. A sub-challenge remains as to how this can be spread as awareness. While this doesn't solve the dilemma, it may bring everyone to common ground from where sustainability can be much more effective.

5.1.2. Engineering Mindset

One of the biggest outcomes of this research was the very interesting take on sustainability by most of the students. This sentiment was unearthed by the researcher on multiple occasions and it was instrumental in solidifying hope in the mind of the researcher [3]. Most students are aware of the issues that climate change poses and the bleak future of the aerospace industry, should we fail to find solutions to global warming. However, they were also extremely confident in their abilities to solve the problem. To them, they see the environment as a hard constraint which needs to be taken into account in their design. Hence, this engineering mindset, which is often criticised for initiating climate change in the first place, is provoked toward pro-environmental engineering. Most students have aspirations which translate to jobs and careers in large polluting industries and domains. They are, however, unnerved by this snag and take it up as a challenge that they need to overcome to define a 'successful' career.

It is the researcher's opinion that the participatory action of the course manager, the TA and the significance of sustainability in the AE1222-I course was instrumental in unearthing the dormant responsibility of the students toward the environment and understanding the nuances that come with aerospace engineering. While it was hypothesised that the technical attitude was an underlying issue which troubled the aerospace sector, it came as a pleasant surprise that many students intend to use this attitude to solve the problem of climate change. It was, indeed, a very hopeful prospect.

5.1.3. Learning Goals

To seamlessly relay knowledge and information to the students, every course has a certain set of learning goals which need to be devised to ensure that the students and the teachers are on track to meet the course outcomes. It is necessary to develop a set of learning goals which can be introduced for sustainability as this can be extremely beneficial for all teaching staff, lecturers and course managers who want to incorporate sustainability into their curriculum. In this thesis, the baseline which was followed was adapted from a non-technical course structure (Ethics for Aerospace Engineers), while ensuring that this is extremely relevant for a technical setting. Additionally, this set of Learning Goals, although was not explicitly mentioned to the students [4], incorporated the Revised Bloom's Taxonomy so that the importance of the existing learning goals is not compromised. This set of learning goals could ideally be plugged into existing courses so that the aspect of sustainability and circularity can be better addressed in new courses.

1. **Sustainability Sensitivity:** The student observes and diagnoses sustainability issues which exist in the current design, process or technology; establishes environmental responsibility and comprehends a situation which can have environmental implications.

2. **Sustainability Analysis Skills:** The student can investigate scenarios which have environmental conflicts and can enumerate the impact of the said conflict; understand stakeholder interests and weigh out those benefits versus the environmental repercussions; quantify the environmental impact of technology, process or design.

3. **Sustainability Creativity:** The student is capable of providing novel solutions by making use of interdisciplinary perspectives to resolve conflicts; recommending or using ingenious results to remove roadblocks in the technology, process or design.

4. **Sustainability Decision Making and Argumentation Skills** The student can utilise environmental responsiveness and make decisions following pro-environmental perspectives; the ability to defend these decisions (environmentally and ethically) after discussions with interdisciplinary (preferably non-technical) teams.

[3] The researcher is sceptic about the aerospace industry and humanity's general failure to mitigate climate change.
[4] as it was a pilot process

5.2. Limitations

This study comes with its fair share of Limitations. While these can be seen as factors which handicap the data collected and the insights drawn, they can also be seen as an opportunity for improvement for future work.

This study was focused on the students of the Aerospace Engineering Faculty. This was due to the thesis being under the broader umbrella of the Circular Aviation lab. Hence, the results will not be generalizable to other Faculties. However, the process which needs to be followed can be very similar and this can be followed, with certain changes specific to the faculty under study. The GreenTU's, Green Thread project can be followed to expedite this process, should any course manager be interested in revamping their course (TUD Education, 2022; Hubert and Weinzierl, 2022).

The method followed to come up with a correlation between the different constructs was solely dependent on mean values. As a study to find correlations between the relevant constructs in a technical University setting (suited for Bachelor engineering students) had not been carried out previously, it was imperative to follow a trial-and-error procedure to come up with the correlational analysis which was important for the scope of the study. A working hypothesis is not present as the researcher was unclear as to what to expect. Hence an Exploratory Factor Analysis was carried out which can be considered a wild card approach, especially in a study such as this one. hence, the correlations could be affected due to this trial and error approach which was followed. The absence of literature was another limitation in this category.

The reliability of the various constructs was extremely low. Usually, for proving reliability, Cronbach's α value needs to be greater than 0.7. While this value was not reached by any of the constructs, the uni-dimensional reliability of the individual constructs was quite significant. These alpha values of the items and the constructs can be seen in Appendix I. These values are a testament to the fact that these measures are capable of being employed in research as indicated by the literature. However, in the case of this thesis, they fall short because of the unorthodox interlocking of these individual measures. It can be a good study in itself to develop a combination measure for all these individual measures. Additionally, the researcher initially intended to employ the Solomon four-group research design as the conditions were right for a pre-test and post-test, both for a control group and the experimental group. However, this method is time-consuming and requires extensive background study which was not feasible for an individual to carry out.

The management of the Action Research could be much more effective if the researcher is given more time in interacting with the students. While time is a constraint in any research, this factor was of particular importance because of the intense workload to which the students at LR are inherently subjected. The researcher is granted only limited time to make an impact as the research takes a back seat to the actual coursework. In any case, it is the responsibility of the researcher to plan for the various workshops, in-depth lectures and interactions that they want the students to feel. As Action Research requires the active involvement of the researcher with the subject of the study, the time factor is all the more important and it would be effective to follow a fixed procedure of introducing creative pathways and methods to get the message and need for sustainability across to the students.

The number of participants in the questionnaire was extremely low (N=32). The sample size was purported to be an entire batch of aerospace engineering students (N=400). The focus group, on the other hand, was a perfect size with 21 students who belonged to two batches (design teams). However, the number of participants in the survey was only 8% of the total class. This turnout was after two official reminders and word-of-mouth prompts. While this sample size was expected due to the issuance of the questionnaire after the completion of the course, it can be improved by sending the questionnaire items at least two weeks before the Peer Feedback session of the course. The internal reliability of the descriptive data can be hence improved with larger sample size. The correlations between the constructs can be better studied so that future work can use those insights to enhance the sustainability module or sub-assignment which can transcend the obstacles and be a lot more impactful to the students. Currently, the correlations are significant but moderate. This can be improved with larger sample size.

5.3. Recommendations and Scope for Future Work

In the event of future research in the area of incorporating sustainability into technical courses is concerned, it would be recommended to employ a student as a TA to aid the course manager in this process. This student should preferably be from another faculty with a passion for sustainability. Additionally, this student should also demonstrate a fervour for the Faculty that would potentially employ her/him (using cross-credit courses). With help from the GreenTeam of the Faculty under study, who can connect to the GreenTU, various students from other faculties can be notified of this opportunity. This choice of a TA from another faculty would introduce an aspect of Interdisciplinarity in the course which can immense advantages within the technical aspects of the course apart from the sustainability angle. On the flip-side, the student would see this opportunity as one which could be a possible career path as there is a monetary motivation behind it.

A campus-wide Green Thread awareness program can aid very well in fixing the limitations of this research. As demanding standards are set at the TU Delft to realise its climate goals by 2030, it is the need of the hour to promote student and teacher interactions via bottom-up course adaptations for sustainability. This can introduce a participatory approach to pro-environmental attitudes at many levels in the University. This recommendation is directed toward Green Teams all over the TU Delft to increase awareness of the existence of the Green Thread.

The introduction of a single course to address sustainability would be futile as its academic value would not be appreciated. While the higher management of the LR is already aware of this, willing teachers at the Faculty could make powerful changes in (all) their respective courses to influence their peers. The existing Ethics courses which are provided by the Faculty of TPM are also advised to adopt sustainability aspects which can be useful in debating complex situations which could pose moral dilemmas, thereby, introducing an interdisciplinary aspect to both these powerful and important themes. The study conducted in this thesis can also be replicated in a Master level course. While the measures and constructs need to be modified, they can provide a treasure trove of knowledge and trends which can help the Faculty become more sustainable at all levels of its education. The Inventory Report created by the AE Green Team can be a good starting point for identifying such a course (Arblaster et al., 2020).

This task of adapting courses to accommodate sustainability would work best with those courses which are practically oriented. Hands-on courses which require students to design and build something would be very suitable for sustainability as this gives the students a very hands-on experience with sustainability. The occurrence of sustainability would be a lot more appreciated when it is presented in an exploratory manner such as a practical course. Since practical group work necessitates students with different skills to come together, this can be a perfect breeding ground for creative sustainability. On the other hand, the value of sustainability is lost if it is introduced in a course like Calculus [5]. The process to adapt courses can be referred to in the section of the previous chapter. It is recommended to follow the Learning Goals presented for Aerospace Engineering courses. In addition, Bloom's Taxonomy is also required to be followed as this ensures that the new modules are academically relevant and produces effective schooling on sustainability issues.

A very important recommendation would be to train Faculty teachers to be open to pro-environmental behaviour. As the students look to teachers as an example, they are a very effective stakeholder group. The introduction of sustainability into aerospace education also requires a lot of experimentation and willingness from the responsible Faculty member. Hence, while it would be useful to work with a Professor who is enthusiastic about the environment, it may helpful for the Faculty to train all staff on the lines of sustainability. This may help to mitigate the dilemma mentioned in section 5.1.1

[5]while it may seem impossible to get this into fruition, it would have negative effects

5.3.1. Recommendations beyond thesis scope

To further improve the landscape of sustainability at the TU Delft, the researcher is including two additional recommendations which are beyond the scope of this thesis. However, these recommendations can be effective when trying to impart the need and urgency for pro-environmental behaviour within the aerospace program at LR. The first one is in the realm of the Bachelor thesis. The Design Synthesis Exercise, which is essentially a Bachelor's thesis, can include a pre-condition of an environmental angle. It would be mutually beneficial to the students and the faculty to carry this out. This could also be followed during the Master Thesis where the condition is much more stringent. This would allow the students to effectively think about the career they choose as aerospace engineers and this also bolsters innovation and expedites sustainable aviation. The second recommendation would be to make the Sustainable Aviation MOOC (DelftX, 2021) a pre-requisite for newly admitted Master's Students as this can introduce the theme of sustainability to the international students who are possibly not introduced to the concepts of sustainability. As most students do a bridging course anyway, it would not be too much to ask for. Additionally, this can also help the students at later instances of their Master's and with their thesis.

6 Conclusion

This study was conducted to explore the various sustainability and circularity challenges which the current aerospace industry is plagued with was carried out to improve the curriculum of the current aerospace engineers so that they would not be recruited into an ecosystem which would be counter-productive to the need of the hour: climate change mitigation. In short, this thesis has explored a certain bachelor level AE course and adapted it to accommodate the realm of sustainability. Additionally, Action research has been conducted where the researcher is in contact with the students to help them gain knowledge in the aspects of sustainability and circularity and this process was mutually beneficial as the researcher was able to gain insights from the students who were taking this particular course AE1222-I.

The main research question and the sub-research questions are as follows:

Main Research Question: ***"How could the education of aerospace engineers be better developed to incorporate sustainability and circularity in their design?"***

SRQ1: How can a bottom-up approach be a suitable method for developing an attitude among students to facilitate circular/sustainable design?

SRQ2: What obstacles exist within the aerospace engineering students that prevent the implementation of more sustainable practices?

SRQ3: What could be a logical framework for the incorporation of sustainability education in all levels of aerospace engineering?

Although the chronology of answering the research questions was contrary to a usual thesis, the incorporation of a bottom-up approach based on Action Research ensured that all these aspects were thoroughly addressed.

MRQ: To develop the sustainability and circularity know-how of aerospace engineers, a bachelor-level course at the TU Delft was identified and was adapted to make the students think critically of an additional design constraint, i.e, sustainability. They were required to quantify their environmental footprint and choose between automated or manual manufacturing processes. They were also made to justify this decision by invoking their calculated environmental footprint. To address the aspect of circularity, the students were expected to utilise the 9Rs of circularity and develop creative and efficient means to carry out their manufacturing task of a wing spar. By means of employing modifying the course from a pro-environmental angle, a lot of the students were invited to think differently and as they were not constrained by conventional thinking, they were able to provide innovative and creative solutions.

SRQ1: To develop a pro-environmental attitude among a group of people, the bottom-up approach has been a proven tool to use. This approach usually forms a social group, which strives to encourage others to become active in preserving the environment and this makes it a compelling approach to undertake, especially when one needs to work against pre-existing hierarchies that control the curriculum. However, support from these authorities is imperative. More importantly, however, is the appeal to collaborate with the stakeholder group with the maximum power and interest in the matter of sustainability, the lecturers and course managers. Hence, the bottom-up approach can be effectuated with the help of a very enthusiastic Faculty member who has the ability and expertise to try inducing pro-environmental behaviours through one of their courses. While this thesis was fortunate to receive such a Professor, it may not always be possible. As the bottom-up approach is from the grassroots, it can make more quintessential changes to the curriculum that can prove effective. It is also usually capable of inducing policy changes at the higher level, should it become successful.

SRQ2: To address the obstacles which exist in the educational system, a qualitative and quantitative study was carried out on the students who took this course and the main obstacles or measures which were identified were the lack of Interdisciplinary learning, Scepticism, Environmental Responsibility and Conflict with Career Goals. Each of these obstacles was quantitatively measured by employing a survey. They were also concurrently studied using qualitative methods such as workshops and discussions. While it was important to come up with correlations between these measures, a list of interrelationships was drawn from both sets of data. It must be noted that all the quantitative correlations were moderate, but they were significant, nevertheless. There was also an interesting link between the perception of selected students who had some well-thought-out responses in the qualitative study. In summary, those students who were high in interdisciplinarity were more sceptic about the environment and climate change. Additionally, The students who scored high in interdisciplinarity and scepticism were also scoring high in Environmental Responsibility. This could be the biggest takeaway from this research and educators should aim to help increase the number of students who are environmentally responsible.

SRQ3: This thesis was built on the foundation of adapting an already existing course (AE1222-I). However, to maintain its academic relevance and efficacious knowledge-sharing capability, the revised Bloom's Taxonomy was followed when developing the additional sustainability and circularity module. This proves very effective because of the nature of the course which was developed. The module was able to make students create a new (novel) design, by justifying an environmental stand in addition to the original design requirements. This was carried out after differentiating various means to develop the design and using a quantification means to apply the environmental impact of the procedure into the equation. This was a practical example of understanding the concept of circularity as a means to sustainability and this ensures the concept has been gained as knowledge. There is also a good amount of reference to the baseline of Ethics to develop new learning goals which can be used for other courses. These learning goals are simple, interchangeable and parsimonious as they can be integrated into the curriculum without a major overhaul of the course overview. It is of the researcher's opinion that these learning goals can be incorporated into other Faculty courses as well, thereby improving the generalizability of the study.

6.1. Reflection on Thesis

In the context of this study, it can be seen that its focus was on the future of the aerospace industry. This caters to a small portion of the aerospace industry and it must be critically noted that this thesis addresses only a small pathway of the big picture which is climate change. Countless research studies are being conducted on novel propulsion methods that can reduce pollution while increasing efficiency. Hydrogen and electric propulsion methods headline these research ideas. There is also another branch of research which explores critical raw materials and other manufacturing processes which can expedite the transition to a circular economy. The use of composites and innovative aerospace materials has always been explored by the scientific community. Other research on cleaning up aviation takes place in the realm of Airport operations, procurement of materials, EOL solutions and LCA of aircraft and the industry as a whole. This shows that multiple pathways exist in mitigating the contribution of aviation toward climate change.

To realise all these pathways, the positive attitudes of engineers toward sustainability are imperative. This thesis focuses on the people and individuals who require a comprehensive mindset change to successfully bring these pathways to fruition. While it may seem like all pathways lead to the same goal, it must be understood that each pathway requires to be traversed to achieve our goals. Hence pro-environmental attitudes are of utmost importance. Climate change is a wicked problem which affects multiple sectors and conflicts with the interests of capitalism. Hence, developing sustainability competencies (Wiek et al., 2011) among the future aerospace engineers today would help reduce the burden of complexity.

The diffusion of pro-environmental attitudes and subsequent social identities should not be restricted to the budding engineers of tomorrow. It should also be quickly adopted by the incumbent engineers. If this is not addressed, there will be conflicts of interest which will be counterproductive. Paletti, 2021 argues that climate change will not wait for our human-centric conflicts of profit and interests and hence everyone needs to be on the same page. A bottom-up approach to sustainability can help in this aspect by incentivising everyone to live a more sustainable life. How this can be realised remains to be seen, but it can be addressed by spreading awareness of climate change in an individual's personal life. Promoting a life of lower consumption and de-growth, which has health and monetary benefits could be a plausible means to propagate pro-environmental attitudes. This attitude invariably rubs off onto the individual's career as well which can have magnified consequences.

Bloom's taxonomy is closely followed in this thesis and it is very effective due to its simplicity and ease of use. The revised taxonomy is called upon to clarify the addition of the sustainability module in the course. As sustainability needs to be embedded in education and not seen as a mere afterthought, Bloom's taxonomy is called upon to supervise the task of inlaying sustainability in education. Another aspect that needs to be understood is that sustainability is no more restricted to environmental engineers and climate change activists. Education, being the biggest form of awareness, needs to necessitate the changes. The sustainability curriculum can be plugged into other courses, by employing Bloom's taxonomy. This taxonomy is built on six levels which are, in essence, requirements. The first step includes **creation** or production of an **original work**. Here, the students were made to design and build a wing box. Secondly, the students are required to **justify** their design choices, especially on the lines of sustainability. After this, they are made to **distinguish** various ideas which they will employ along the lines of circularity in their design. The next level entails **applying** this information in a new situation. As this design project provides a perfect opportunity to do so, it is ideal for circular design ideas. All these above levels are instrumental in aiding students **explain** the concept of sustainability. Finally, it can be seen that the student **remembers** the concept in the real world where it matters the most. This is hopefully seen in the student's personal life and future career. It can be argued that using Bloom's taxonomy in other design courses can increase the chances of sustainability becoming a way of life in these students' lives.

Any research or study is required to be replicated in distinct scenarios and environments to understand its external validity. Hence, this thesis comes under scrutiny for its effectiveness in other Faculties at TU Delft, for starts. Here, the researcher argues that the improvement of education can occur by following the same steps presented in this thesis. In essence, the Sustainability Learning Goals are presented in Section 5.1.3 and the Bloom's Taxonomy which is discussed in Section 2.6.1. However, the generalizability of this research has certain conditions which would make it effective. Firstly, the course which needs to be adapted requires a group setting of three or more students to involve an interdisciplinary perspective. Secondly, the course should ideally be a design course which requires the students to create something related to technology [1]. If the course is not related to design, the topic chosen must be related to a sustainability-oriented ethical issue or conflict. Even the fundamental engineering courses can all have aspects of sustainability if needed, but this is not recommended. Courses which only contain an exam should ideally be left out of the scope of sustainability modules because this would seem like a forceful form of education. Discussions in these courses, however, would be a welcome change as this propagates pro-environmental attitudes and can sow some good ideas among students.

[1] For example, the Master course Aero Engine Technology (AE4238) required students in groups of three to design a flying car which ran on electricity.

6.2. MoT Master Program Reflection

This thesis was conducted to fulfil the partial requirement of the MoT Program which is provided by the Faculteit Techniek, Bestuur en Management (TBM)[2] at the TU Delft. While this thesis is targeted to adapt the educational program of the Faculty of Aerospace Engineering, it ultimately makes up a thesis for the Management of Technology program. Hence, the thesis is required t meet a certain set of requirements as elaborated by Verburg, 2020.

The analytical component which is addressed can be classified as the current requirement of improved aerospace educational methods which can benefit the future aerospace industry. As the research also focused on pinpointing correlations between the various factors that influence sustainability among students, it can be seen as an analytical approach. This is also seen in the data collection means which were both qualitative and quantitative. The thesis was instrumental in stitching together two separate faculties at the TU Delft and hence its multidisciplinary approach speaks for itself. As the thesis applies to most Faculties at the TU Delft, this can be further classified as interdisciplinary nature. Finally, the research is focused on the technical domain of aerospace engineering education. As it involves adapting the pedagogical system of an acute technical branch of education, this requirement is also checked.

The influence of MoT in this thesis is profound. The thesis incorporates elements from multiple courses which are part of the MoT curriculum. The understanding of the barriers and means to improve educational practices can be classified as knowledge which is stressed in the course **Leadership and Technology Management (MOT1524)**[3]. The research is, in its way, propagating the focus toward value-sensitive design which is the theme of the course **Technology Dynamics (MOT1412)**[4]. Finally, this research employs a mixed method study which entails data collection (qualitative and quantitative) and action research as fundamental parts of the study. These research methods were studied in the course **Research Methods (MOT2312)**.

The various recommendations mentioned in Chapter 5 can also apply to the MoT program. While the program is drastically different from Aerospace Engineering, the basic requirement for most courses is group work. As this inherently provides a breeding ground for interdisciplinary teams, the aspect of a dilemma which addresses sustainability can be added as a pre-requirement for project work. Similar requirements in courses like **High Tech Marketing (MOT1534)**, **Integration Moment (MOT1003)** and **Inter- and intra-organisational decision making (MOT1452)** can also be explored with good results as these are group courses where students choose their topics. Additionally, a Master Thesis topic which possesses a sustainability challenge can be prompted by Project supervisors as an issue which requires to be addressed while choosing a topic. The multi-disciplinary nature of Climate Change will not complicate students' options as most current technologies have a non-sustainable angle which is waiting to be explored and improved upon. The course **Social and Scientific Values (MOT1442)** already explores various ethical dilemmas and introducing an ethical dilemma which has its root in unsustainable practices is an easy way to bring this research closer to the Faculty of Technology, Policy and Management.

[2]Faculty of Technology, Policy and Management
[3]Prof. dr. ir. Robert Verburg is the responsible instructor
[4]Dr. Ir. U. Pesch is a responsible instructor

A

AE1222-I Sustainability Angle

IAC has recently been in the spotlight for not being transparent with their environmental impact. There has been immense pressure from the government to all engineering firms to be more accountable about their emissions and this stems from the United Nations Climate Change Conference (COP26) which was held at Glasgow in 2021. While DELTA is extremely happy with IAC's work, it expects to deliver a 'Sustainable and 100% recyclable sailplane'. This means that DELTA also expects its suppliers to share in its vision for the planet and the environment.

In light of these external pressures, IAC is forced to make their design more sustainable or face the risk of losing out on Project Feather Wing to a competitor. Hence IAC requires it's engineers (students) to take the first step in identifying the various pathways through which they can chronicle their environmental repercussions. This would be a step in the right direction in order to achieve the elementary understanding of sustainability. The United Nations has developed a host of 17 different sustainable development goals (SDGS) which were the result of the UN conference on SDGS in Rio de Janeiro, 2012. These goals can be, in essence, a good starting point to begin with. You are tasked to identify the SDGS which need to be achieved to tackle climate change primarily.

While sustainability needs to be achieved in design, quantifying your environmental impact would be of utmost importance so that decisions and processes can be carried out to reduce its adverse effects. Therefore, you are required to document your environmental impact of building the wing box/spar and suggest means to reduce this footprint so that it is in line with various stakeholder requirements. You are required to be critical and creative in your thinking and consider all the forms of emissions which need to be quantified. As DELTA is also responsible for their own emissions, it requires IAC to provide it's share of emissions so as to be responsible and accountable on all levels of it's supply chain. This is also in accordance with the COP26's discussions on making environmental impact everyone's business. This constitutes the direct and indirect emissions which are also referred to as 'scopes'.

It is a very well-known fact that global warming due to greenhouse gases are the primary reason for accelerated climate change. As IAC contemplates their new requirements, they realise that they have an obligation to the environment more than simply following a set of rules which aligns them to their clients. In fact, as Project Feather Wing's tagline also requires a recyclable aircraft, IAC's engineers want to incorporate principles of a new economic model which is conducive to accomplishing environmental goals. Historically, IAC has been following the Linear Model, which follows a "Take-Make-Use-Waste" philosophy. Multiple studies have shown that this model is not sustainable and creates a lot of waste in the form of end products which have little value after their primary purpose has been fulfilled. As IAC wants to be seen as a company which takes the environment seriously, while still functioning as a business, it aims to adopt a new way of doing things called the Circular Economic Model.

In principle, the Circular Economic Model follows the doctrine of "Waste is Food", where the waste of one industry or business becomes the food (raw material) for another. This ensures that materials are always reused, lesser emissions are released and more value is derived from every industry.

Additionally, recycling could be carried out at the end of the value chain and the processed materials become raw materials again. This concept of the circular economy requires careful design which IAC would be required to follow. As most specialised aerospace parts are not easily reused, a systems design approach has shown the most promise when it comes to incorporating the circular economy into a value chain.

After discussions, the objective of incorporating circularity into the wing box/spar design has been welcomed readily by DELTA. They are, however, very sceptical about the value of the final product as they believe in high standards of quality and reliability. You are challenged to use a framework of the circular economy in your design which can ensure that there is no compromise on quality, but also gives your product value after it's purpose has been fulfilled. A systems design approach (which envisions design for incorporating a circularity) can be followed. You will be required to choose from the 9R framework and provide reasons for your design choices, suitable applications for end-of-life use and strategies which the industry can adopt to become circular, which directly reduces emissions and positively impacts accelerated climate change.

A.1. Preliminary Questions:

1. What emissions would you focus on in order to quantify IAC's environmental impact?
2. Which SDG would this emission be classified under?
3. Which SDG would this emission be classified under?
4. What are Scope 1, Scope 2 and Scope 3 emissions?
5. Which Scope of emissions would be most applicable to IAC's work?
6. How would you quantify the Scope of emissions mentioned in the previous question?
7. How can the Circular Economy help the environment?
8. What are the 9R's of the Circular Economy?
9. Which of the 9R's would be applicable to the wing-box/spar design?
10. Discuss two effective ways by which the 9R framework can be incorporated into your project.
11. Discuss in-depth the issues you face when trying to incorporate sustainability/circularity in your design.

Table A.1: Rates for Manufacturing Categories (M. J. Schuurman, 2021)

Category	Rate / hour (EURO)	Environmental Footprint
KUKA Robot	1000 + 250	
Manual	90/person + 35	
Hybrid	Custom	

The emission factors for the Netherlands can be referred to from Table A.2 [1].

A.2. Questions:

1. Review the comprehensive choices you had to take to ensure your design was compatible with quantifying emissions and suggest critical measures by which these emissions can be reduced within your project team (introspect your team and individual consumption of resources at every step of the project).

[1] Chain emissions from power stations and production resources are not included in the total.

Table A.2: Emission Factors for the Netherlands, 2019 (van der Niet and Bruinsma, 2022)

	Production (gCO2-eq/kWh)	Chain emissions excluding central and means of production (gCO2-eq/kWh))	Chain emissions from central and means of production (gCO2-eq/kWh)	Total[2] (gCO2-eq/kWh)
Total Electricity Mix (100%)	369	58	5	427
Grey Electricity Mix (81%)	454	69	1	523

2. IAC plans to scale up production of the wing box/spar and hence it is critically considering its environmental footprint in this expansion. Compare the emissions produced by the KUKA, Manual and Hybrid categories and advise IAC regarding which form of production will be environmentally friendly and defend this by numerically quantifying the emissions for X number of wing box/spar's over the course of 1 year.
3. How can you outline your entire design and production process by taking the 9R framework of Circularity into consideration? Explain this with creative examples in your case and account for sustainable solutions after your design has completed it's purpose as a wing-box/spar.
4. Discuss in-depth the issues you face when trying to incorporate sustainability/circularity in your design.

B

Workshop 1: Outline

Workshop: Environmental Measures for AE1222-I

B.1. Disclaimer

Not graded and ask students to be brutally honest for improvement of education and better future course structure. Use the help of Green team TA (Kiva)

B.2. Video 1

1.5 degree C vs. 2 degree C: What half a degree of warming could mean for climate change A short introduction to climate change and what it means for the earth at the end of 2100. No mention of aviation and it's contribution. Basic high school science and introduce examples of CO_2 and it's warming effect.

B.3. Q and A session

Q and A session (Break out frames in Miro and locked frames to prevent bias. No mention of titles. Request age and nationality)

Miro Workshop Presentation

The questions can be found in Appendix C

B.4. Video 2

SUSTAINair Animation - Circular Economy for Aviation & Aerospace Sectors

Introduce the effect of aviation in global climate change and talk about a way of effectuating change in the aviation industry. Recap of the reader (AE1222-I) and talk about economies (Linear, Circular, Degrowth, etc.)

B.5. Problems which you faced

- An in-depth discussion of the various sustainability challenges which each team faced in their project. Debate the choices made for the quantification of carbon emissions by using the KUKA Robot and/or a hybrid method.

- Come up with novel ideas which can be derived from the 9R's of circularity in aviation (definitions in reader)

- Notice the similarities and differences for each team.

- Derive insights and look for competencies.

B.6. Final Question and Game

Introduce the Climate Change Game and ask students to essentially reach net zero by 2100. Brief them about the intricacies and help them try for themselves.

- En-ROADS: Climate Simulation Game 1 - Climate Interactive, MIT Sloan Sustainability Initiative and Ventana Systems
- Financial Times: Climate Simulation Game 2 - Can you reach net zero by 2050?

For reflection: "If we make aviation more efficient, will this increase demand for flying which could possibly increase global air travel thereby giving impetus for more emissions?"

C

Workshop 1: Questions

C.1. Career Goals

1. The career and goals you set for yourself have a very profound impact on climate change. Being an aerospace engineer, means believing that you can make people's lives better through connection, fast travel and sharing of experiences. How do you think this falls in line with sustainability?

2. What kind of aerospace engineer do you aspire to become? Would you pursue your Master's at TU Delft? Which area of aerospace would suit you perfectly?

3. Would your career choice conflict with sustainability goals because aviation is a big part of the emissions problem? If and if not, how can you solve them?

C.2. Environmental Responsibility

1. Are you as an individual responsible for climate change?

2. Will you be working in an industry that is inherently polluting and would you be responsible for its contribution?

3. If you do not feel individually responsible, are you collectively responsible for the problem?

C.3. Uncertainty

1. If climate change is indeed happening, how much is aviation responsible for it?

2. Will any action through technology or innovation help slow down the problem? Are we working in vain?

3. Should you give up your career dreams and aspirations because of climate change? If not, what should change?

C.4. Interdisciplinarity

1. Do you think ONE course on sustainability/environment will be enough to imbibe the urgency of the problem? Or do you think every course needs to have a sustainability angle to it? Elaborate.

2. As engineers, we often forget that the world has other aspects which need to be addressed for our technology to thrive like economics, policy, politics and social sciences. Do you think these need to be taught to engineers?

C.5. Scepticism

1. Do you believe climate change is real? Is it being exaggerated by older people who have enjoyed the benefits of burning fossil fuels all through their life?

2. Do you think even with our best efforts, we will not be able to meet our climate goals by the end of the century? Why?

3. If one unique solution does not exist to climate change, should aviation continue as usual because it is a very efficient means of transport.

C.6. Temporal and Academic value

1. Is there too much coursework in the bachelor program to accommodate sustainability in each course?

2. Is there time to address the sustainability aspect in a course given the value it holds for the final grade?

3. Do you think teaching students about sustainability in aerospace engineering is hypo-critic? Is it a waste of time for future aerospace engineers who are working on tools of 'mass-pollution'?

D

Workshop 1 Responses

D.1. Career Goals (M1)

- **Student 1 (S1): 19 Luxembougerish**
  1. R1: I believe there is no point going against progress or change such as the growth of the aviation sector thus one can only try to make positive impacts on future developments.
  2. R2: I aspire to work in the space sector.
  3. R3: No comment
- **Student 2 (S2): 18 Dutch**
  1. R1: Not considering sustainability will, in the long run, degrade people's lives, as the environment and economy will become less livable. As a consequence, the demand for aerospace services might drop and peoples lives will not be made better
  2. R2: No Comment
  3. R3: It will not have to conflict, as I am interested in designing hybrid or fully electrical planes, in the hope to make flight sustainable.
- **Student 3 (S3): 19 Spanish**
  1. R1: I think that it is very important to be able to continue expanding the aerospace industry, and be able to do it in a sustainable way. However I think that there needs to be a way to do it sustainably in a cost effective way, since if being sustainable were cheaper, almost every company or airline would take this route. Accordingly I think its going to be harder to achieve a global sustainable setting.
  2. R2: No Comment
  3. R3: No comment
- **Student 4 (S4): 18 Dutch**
  1. R1: I think if we want it enough these things can be combined.
  2. R2: I think i want to go into space and probably will do my masters in Delft
  3. R3: I don't think so, since aviation will exist anyhow it is best to try and work in the field to make it more sustainable.
- **Student 5 (S5): 20 Polish**
  1. R1: Aviation provides a way of cheap and fast travel. However, this should be true even in the future.
  2. R2: I want to pursue a Master's degree at TU Delft; I hope to work in the area of aerodynamics or propulsion.

3. R3: Area of propulsion especially is responsible for the emissions in aviation. It's important to focus efforts on alternative/sustainable propulsion solutions.

- **Student 6 (S6): 19 Dutch**
  1. R1: I think if you keep in mind the emissions of production and traveling you can reduce it and be sustainable as much as possible
  2. R2: I haven't really thought about it yet, but i will definitely do a master at the TU Delft and maybe something that includes aerodynamics. Because I am really interested in top sports.
  3. R3: No Comment
- **Student 7 (S7): 19 Italian**
  1. R1: Aerospace engineering, as with engineering in general, is all about optimizing design, including its level of sustainability.
  2. R2: I am rather interested in the field of propulsion, so I think I will be pursuing a Master track most similar to that one.
  3. R3: My interest in propulsion also stems from the need to find new and more sustainable ways of powering our aircraft.
- **Student 8 (S8): 18 Dutch**
  1. R1: My goal is to work in motor-sport, working on sustainability. Events like formula E and extreme E that deliver the thrill of racing but they have as main goal to develop sustainable technology for daily drive cars, and leave a positive impact on the race locations.
  2. R2: No Comment
  3. R3: No Comment
- **Student 9 (S9): 18 Dutch**
  1. R1: Aerospace engineering career helps with thinking about the future, so the career in aerospace engineering helps you solve sustainability problems.
  2. R2: I aspire to become an engineer that goes the next step in thinking about future goals and plans. To be honest, I haven't given much thought to what my masters will be, where I will do it, or even which area fits me. Though my preference goes out to space.
  3. R3: Not necessarily. I think that party of my career will be improving the problems aviation and space travel face this day.
- **Student 10 (S10): 18 Polish**
  1. R1: I believe that since currently air transport is very pollutant, there is much room to improve, and I'd like to be a part of that.
  2. R2: Id like to pursue the master in wind energy, I think it suits me best, and can also have a great impact on world's sustainability.
  3. R3: It would not, as I could be working in order to improve them.
- **Student 11 (S11): 19 Spanish**
  1. R1: Aerospace is closely related to sustainability as this study deals with a main transportation mean , which is a great source of contamination and climate change.
  2. R2: Space engineering is my main interest. This would conflict with sustainability as a lot of fuel is burnt to launch rockets daily and we can always make them cleaner.
  3. R3: No Comment
- **Student 12 (S12): 19 Italian**
  1. R1: Aviation is one of the industries with the biggest impact in sustainability, thus it is important to keep in mind the environment when making any choices.

2. R2: I am still not sure about whether to pursue my Master's degree at TU Delft, but I would like to get a Master's in aerodynamics or propulsion.
3. R3: I believe that is possible to work towards a better aviation / space sector, especially regarding flights and the type of propulsion used.

- **Student 13 (S13): 22 Dutch**

1. R1: Honestly, I haven't put much thought into it.
2. R2: I would like to work in the spaceflight industry and there is a spaceflight masters at the TU Delft.
3. R3: Most likely, however I do believe that with time technological solutions can be found for most issues regarding the environment.

- **Student 14 (S14): 18 Dutch**

1. R1: If due to sustainability, traveling has to become way more expensive, people will travel less.
2. R2: I do not know yet if I want to stay at TU Delft, im also net yet figuring out what master to choose.
3. R3: It might indeed conflict with sustainability, as almost everything will. solving that would be a whole study on its own

- **Student 15 (S15): 20 Japanese**

1. R1: As an aerospace engineer our work is only useful when people are able to and desire to travel. If the world falls into disrepair due to global warming, the world will have bigger problems than designing better planes to fly on. Therefore, it is necessary to maintain the Earth's well-being to continue our work.
2. R2: I aspire to become a successful aerospace engineer. At this early stage of my career, I do not know what that "success" is defined by, much less the concentration I would like to focus on in the future.
3. R3: If there was absolutely no way my certain career would be able to improve in terms of sustainability, then yes. However, I cannot think of any career or industry that is so.

- **Student 16 (S16): 19 Moroccan**

1. R1: The aviation industry can offer an alternative to transportation through a means of transport that can meet the demands of many people, offering fast and simple travel, while still being more sustainable than cars for example.
2. R2: I don't know what king of engineer I want to become, but I plan on continuing my master at Delft.
3. R3:I am not sure.

- **Student 17 (S17): 19 Dutch**

1. R1: Making the industry more efficient leads to less emissions.
2. R2: I would like to pursue a master however I haven't really looked at all the possibilities yet.
3. R3: No, it is up to engineers to make find solutions to achieve the sustainability goals.

- **Student 18 (S18): 19 Portuguese**

1. R1: Can find alternative options to make travelling more sustainable (AeroDelft for example)
2. R2: Yes I would pursue a Master´s at TU Delft, related to space.
3. R3: It would, but new discoveries can be made on the way which could turn everything more environmentally-friendly and solve other environmental issues on Earth.

- **Student 19 (S19): 18 Burkinese**

1. R1: More sustainable ways of transport!
2. R2: I don't know yet, but I think I will stay at TU Delft.
3. R3: No, because we also learn about sustainability during our courses so I believe I'll eventually reduce the impact of aviation on the climate.

- **Student 20 (S20): 18 Dutch**

1. R1: The aerospace business has a major role in global warming so it is to us aerospace engineers to fix this.
2. R2: Space
3. R3: Definitely not. Aerospace engineers have a critical way of thinking because you operate in extreme conditions.

- **Student 21 (S21): 20 Austrian**

1. R1: For a sustainable future, we need sustainable transportation. So the topic of aerospace and sustainability is closely tied together for the future. I want to become a influential aerospace engineer.
2. R2: No comment
3. R3: No comment

D.2. Environmental Responsibility (M2)

- **Student 1 (S1): 19 Luxembougerish**

1. R1: I believe that as a privileged individual who has choices and options in every day life such as travel, food choices etc.. I am responsible for making greener choices and trying to limit my impact.
2. R2: Most industries are bad for the environment in one way pr another, I think we are responsible for trying to make the industry greener.
3. R3: We are collectively responsible but so are politicians and huge companies.

- **Student 2 (S2): 18 Dutch**

1. R1: You are responsible as an individual for the amount you pollute yourself, but it should be everyone's duty to work together to reduce the total amount of climate change as much as possible.
2. R2: You would be partly responsible for the pollution caused by your products, but the consumers carry shared responsibility. You are even more responsible if you do not try to reduce its contribution.
3. R3: Everyone carries part of the responsibility for the same planet.

- **Student 3 (S3): 19 Spanish**

1. R1: I think I am an individual responsible for climate change, but I could do more to contribute in my everyday life.
2. R2: I think there is a high chance that I will be working in an industry that contributes highly to pollution, and hence would need to consider the impact my actions have on this.
3. R3: I do feel individually responsible, but I feel that however much I may do, either good or bad, is insignificant compared to the effect of larger corporations or industries.

- **Student 4 (S4): 18 Dutch**

1. R1: I don't think most individuals, with some exceptions are responsible for climate change, since they have a very small role in it.
2. R2: Maybe a bit but I think it would also be nice to try to help change the industry.

3. R3: Maybe a bit, but not a lot. A lot of pollution comes from industry and most people don't control that.

- **Student 5 (S5): 20 Polish**
  1. R1: Yes, but so are the industries as a whole. A person should be responsible for the emissions they produce, but the responsibility should be also shared by the industry.
  2. R2: Aviation industry is, at this point, a highly polluting industry. However, this could change in the future. I hope to push that change.
  3. R3: As per Q1, the responsibility is shared between users and the industry. People are aware of the pollution created by airplanes, yet they still use them. The same is true for air
- **Student 6 (S6): 19 Dutch**
  1. R1: Yes, if you do not start yourself with improving the climate other people won't do it either. So start first yourself because you can make a change.
  2. R2: Yes and I think if you are working in such an industry you should really take the pollution into account and think of a way to reduce it or if it is not possible you need to pay extra for the pollution or something.
  3. R3: Yes
- **Student 7 (S7): 19 Italian**
  1. R1: Yes.
  2. R2: I will be working in a sector that actively contributes to pollution and is working towards its reduction.
  3. R3: We are also collectively responsible for climate change.
- **Student 8 (S8): 18 Dutch**
  1. R1: As individuals we're all responsible for climate change. I try to do as much as possible to reduce my carbon footprint by not eating meat, and traveling as little as possible and only using train bike or electric car.
  2. R2: Since my goal is to work in motor sport, it is a bit conflicting. After all this still is an industry that has a lot of pollution for only entertainment. that is something i want to improve while working there.
  3. R3: No
- **Student 9 (S9): 18 Dutch**
  1. R1: Yes, I believe that we as individuals can make the changes needed to reduce climate problems. If everybody thinks that way, It will be good.
  2. R2: Reducing your personal emissions is a good step towards better planet. We as a society are responsible for it, but the blame is not on individuals.
  3. R3: Yes
- **Student 10 (S10): 18 Polish**
  1. R1: I believe that people as individuals are not particularly responsible for the climate change, however by raising the awareness among others, and by working as a whole society, the change (improvement) to the global pollution can be significant.
  2. R2: I don't know yet where ill be working for sure, but no matter what industry that would be, it would not make ma responsible for this contribution. However, there is always room for improvement for the pollution and id like to be working on that.
  3. R3: Yes, I believe that working in a society can have a huge impact on the environment.
- **Student 11 (S11): 19 Spanish**

1. R1: As an individual we are responsible for climate change. So if I would work for a company that pollutes I would be contributing to climate change as every individual can try and make a change. Even if we do not achieve to solve the problem if we are not trying we are indeed contributing to it.
2. R2: No comment
3. R3: No comment

- **Student 12 (S12): 19 Italian**

1. R1: I absolutely believe so, even though I try to be as environmentally conscious as possible. But the biggest problem is us as a society in general
2. R2: Most likely yes, even though I think there is the possibility to bring the industry towards a greener future
3. R3: As I said before, as a society we are responsible for the problem, some more and some less but nevertheless responsible. At the same time I believe that we, as a society can still try and solve the current situation

- **Student 13 (S13): 22 Dutch**

1. R1: I do consider myself more responsible that most, because I am a pilot. But I do not believe that a solution can be found by working alone.
2. R2: Unfortunately yes, as I am currently a pilot let alone future work in Aerospace.
3. R3: I think that only by working together a solution can be found for climate change and by focusing on any one individual would likely be unhelpful.

- **Student 14 (S14): 18 Dutch**

1. R1: Not only I am responsible, everyone as a group are responsible. 1 change on 7 billion will not do much.
2. R2: if I would be working in an industry which is inherently polluting, then also I am contributing to this polluting. It just depends on how much I can change that on my own in this company.
3. R3: Yes I am collectively responsible. We can only do this together, not individually.

- **Student 15 (S15): 20 Japanese**

1. R1: Responsibility of the entire world's climate change cannot be placed upon any individual.
2. R2: The industry I plan to work in is currently largely responsible for polluting the atmosphere. While I may not be responsible for contributing to its pollution, I may become responsible of the industry not improving itself in the factor of sustainability.
3. R3: Yes. It is impossible to pin this responsibility on one individual. We all affect the Earth as we live, and must all take responsibility.

- **Student 16 (S16): 19 Moroccan**

1. R1: I do believe that I am partially responsible for climate change.
2. R2: If offered, I would work in an industry that pollutes, but I wouldn't consider myself responsible for its contribution.
3. R3: I think it's the higher-ups that are responsible, since they are the ones that can change things.

- **Student 17 (S17): 19 Dutch**

1. R1: Yes, your way of life contributes to the climate change
2. R2: If the industry is on track to reduce its impact then yes

3. R3: It is also a collective problem because we live together on this planet. Its not really useful if only half of the people try to make the world a better place if the other half continues.

- **Student 18 (S17): 19 Portuguese**
  1. R1: Everyone is responsible, but yes I also try to decrease my responsibility towards this issue.
  2. R2: Probably, I don't know yet. Maybe I will work instead on a company that tries to decrease pollution related to aviation.
  3. R3: No comment
- **Student 19 (S19): 18 Burkinese**
  1. R1: Yes
  2. R2: If I have no choice, yeah probably
  3. R3: N/A
- **Student 20 (S21): 18 Dutch**
  1. R1: As an individual you cant be responsible, but it is good to have principles.
  2. R2: It is possible that i will be working in an environmentally unfriendly business and i of course would be partially responsible.
  3. R3: I would feel individually responsible, but the only way to tackle the problem is as a collective.
- **Student 21 (S21): 20 Austrian**
  1. R1: Yes, I as an individual am responsible for climate change. I use energy that some times does not come from the greenest sources. I would be working as an aerospace engineer in a polluting industry , but i don't believe I am responsible, because the goal as an aerospace engineer in the future is to cut emissions. I believe we are the solution and not the problem.
  2. R2: No comment
  3. R3: No comment

D.3. Uncertainty (M3)

- **Student 1 (S1): 19 Luxembougerish**
  1. R1: would say in terms of just emissions probably 30%.
  2. R2: Technology is the only way to slow down the problem, through electric or hydrogen planes.
  3. R3: Any career can probably be related to some negative climate effects, I believe that on the contrary, as a environmentally aware individual I have a responsibility to reduce the impact of the industry.
- **Student 2 (S2): 18 Dutch**
  1. R1: Yes I think it is happening and aviation is responsible for like 2% of emissions, so also 2% responsible I think, but it's also part of an entire economy which is also contributing even more, so that aviation cannot be seen as the single party at fault for their contribution
  2. R2: Yes, the emissions might never be zero for lange range planes or heavy cargo, but can be reduced a lot will new innovations.
  3. R3: No, I will try to reduce climate change and even if I cannot, I am not prepared to stop my career dreams for the personal responsibility.
- **Student 3 (S3): 19 Spanish**

1. R1: I estimate aviation to be responsible for about 10% of global emissions.
2. R2: I think innovation would indeed slow down the problem, but for a much longer term i think reversing effects would be needed, as in its not enough to stop the climate change from getting worse, but we should also try to improve the current situation.
3. R3: I believe dreams and aspirations should include the climate change concerns and thoughts, and so on.

- **Student 4 (S4): 18 Dutch**
  1. R1: I think aviation has quite a big impact, I think it's something like 20% of global emission
  2. R2: I do believe that technology can help reduce aviation emissions, but in order to solve climate change, the industry might also have to shrink, especially when it comes to short-range flights.
  3. R3: I don't believe so I think if we give up on the aviation sector, it will remain a big pollutant Aviation is a great technology that will always remain important.
- **Student 5 (S5): 20 Polish**
  1. R1: A few percent; not a lot at the moment, but predictions show this could increase in the future (if other industries meet their emissions reduction goals).
  2. R2: Technology could help to solve the issue. However, realistic estimations shows only a partial success, assuming an exponential growth in industry size.
  3. R3: Depends on the career goals; if a person dreams of work in an industry inherently reliant on burning fossil fuels, its probably not the best idea to pursue that goal.
- **Student 6 (S6): 19 Dutch**
  1. R1: I do not know the exact percentage but it is a big part for the climate change.
  2. R2: Yes maybe another fuel source like hydrogen.
  3. R3: No, there is a lot of work in aviation to make it more climate proof and it will always be needed so you better make it better.
- **Student 7 (S7): 19 Italian**
  1. R1: There is no denying that aviation is contributing to pollution, although it is definitely not the most influencing sector.
  2. R2: We are definitely not working in vain, as any progress that is made grants us with more time to make even more progress.
  3. R3: Do not give up your dreams and aspirations for climate change. The world will be made better faster if you do what you are best at and what you are most passionate about.
- **Student 8 (S8): 18 Dutch**
  1. R1: I think aviation is one of the biggest contributors out there, especially if you consider the fact that there are already alternative means of travel that are much better.
  2. R2: However we can do a lot by innovation. Many people say for example that it's impossible to fly electric, but we work in an industry that has always done impossible things(if you would go back in time and tell people we can fly they wouldn't believe you)
  3. R3: No Comment
- **Student 9 (S9): 18 Dutch**
  1. R1: I think collectively less than cars. Although the sustainability in aviation can be much better, there are multiple other sectors which are much worse and where I think we should lay our focus on.
  2. R2: We could, but I don't feel like it is possible in this society. Most people are too self-centered to think and act clearly and responsibly with the thought of the future.

3. R3: It is best to combine the two. Never give up your hopes and dreams of course, but there are always ways to combine a career of your liking with something that is good for the environment, like designing sustainable aircraft.

- **Student 10 (S10): 18 Polish**
  1. R1: Aviation is responsible for it to a large extent, therefore, through technology we can improve it.
  2. R2: Yes, of course. Consider for example the zero emission hydrogen aircraft.
  3. R3: Of course not. Giving up my career on its own will not change the climate around, I think there is a better way to contribute to stopping the climate change

- **Student 11 (S11): 19 Spanish**
  1. R1: Aviation is maybe not the main contributor to global warming but it is indeed a great responsible for it as millions of planes fly daily. I believe we will be able to reduce our contamination in aviation as there are many innovative solutions that are appearing every year like hydrogen planes or new and more efficient designs. So I think we will eventually achieve a reduction. I would not give up my career for climate change but construct my career around it in order to help and solve the problem.
  2. R2: No comment
  3. R3: No comment

- **Student 12 (S12): 19 Italian**
  1. R1: Aviation is one of the industries with the biggest environmental impact, but at the same time I believe it is one of the industries that can change the most.
  2. R2: There are currently a lot of studies/ trials for a ”greener” aviation sector (not as much for space though) that in my opinion could make the industry more sustainable.
  3. R3: I do not necessarily believe that I’ll have to change career dreams, but I think it is important to keep in mind the environment and try to make positive changes as much as possible.

- **Student 13 (S13): 22 Dutch**
  1. R1: I believe that right now aviation contributes roughly 2-3% of global carbon emissions
  2. R2: Although right now there a no developed solutions to pollution regarding aviation, however I am do believe that with enough time a solution can be found.
  3. R3: No, instead try to bring change within your respective field/industry.

- **Student 14 (S14): 18 Dutch**
  1. R1: Aviation has always played a big role in climate change, exactly how much in a percentage I do not know.
  2. R2: Every little bit will help. Every millionaire also once started with 1 euro.
  3. R3: No you should never do that. Just change your dream in such a way that it takes climate change into account. It will just be another requirement on the list. Just like the other requirements, it has to be met.

- **Student 15 (S15): 20 Japanese**
  1. R1: Aviation definitely plays a role in climate change, however, not as much as the emissions from cars and other road vehicles.
  2. R2: Innovation in technology can help slow down climate change by reducing carbon emissions through use of alternative, ”green” resources.

3. R3: Climate change merely poses another problem for engineers to solve through their innovation. My dreams will not change unless drastic measures are taken at a level that I cannot control.

- **Student 16 (S16): 19 Moroccan**

1. R1: I don't think aviation is greatly responsible for climate change.
2. R2: I believe that with the advancement of technology it will be possible to minimize global warming.
3. R3: I wouldn't give my career, because I have no power on the matter. If I were to refuse the job, there would simply be someone else to take my place.

- **Student 17 (S17): 19 Dutch**

1. R1: Aviation is a big factor but not the biggest. There are many things that can be improved.
2. R2: Yes, innovation could lead to more efficient engines which produce less emissions or emission free engines.
3. R3: No, its up to you do something about it.

- **Student 18 (S18): 19 Portuguese**

1. R1: Has a big impact but is heavily dependent on the demand for flights
2. R2: Yes, there are many options such as hydrogen.
3. R3: Maybe not give up but adapt them to find alternative which are more sustainable

- **Student 19 (S19): 18 Burkinese**

1. R1: Relative to other factors, not that much, but in absolute numbers it is very responsible for it.
2. R2: Yes, and people are working on that.
3. R3: No, I should try to reduce the emission factors, and that's achievable by pursuing actually my career.

- **Student 20 (S20): 18 Dutch**

1. R1: I think aviation plays a major role in climate change. Especially commercial flights are largely responsible.
2. R2: Advanced technology helps, but doesn't solve. I think the solution would be a combination between more advanced aviation together with more strict laws about the amount of aviation.
3. R3: No of course not. Not participating and staying away is even worse. Only by working in the industry you can make a change.

- **Student 21 (S21): 20 Austrian**

1. R1: Aviation has a big impact on the climate. Yes actions will help slow down the problems especially in the long run. (is there a long run?). Climate change will shape future careers.
2. R2: No Comment
3. R3: No Comment

D.4. Interdisciplinarity (M4)

- **Student 1 (S1): 19 Luxembougerish**
  1. R1: I think every course should include sustainability, however it's hard to pr say teach it as there is no solution right now, it is more bringing it up as a problem or discussion than a course.
  2. R2: I think we should have some knowledge of the world but I think the projects we have provide it to some extent. I think a course in economics or such could only be beneficial, for example the minor could be a choice of some social science. I also think politicians should have knowledge pf technology before talking about it.
- **Student 2 (S2): 18 Dutch**
  1. R1: I think one course about this subject would be boring and students would quickly lose interest, maybe even making the course counterproductive. I think if it is a small part of (almost) all courses, the professors can very specifically explain how sustainability can be improved for their coursesubject and it will be more interesting for the student and more effective against climate change.
  2. R2: I think it needs to be taught to a slight extent, but mainly so we can more easily communicate with non-engineers, not because we need expert understanding about it, because that will be too much to ask from an engineer. This could form one or two courses.
- **Student 3 (S3): 19 Spanish**
  1. R1: I think we should be taught a lot more about all the other aspects that influence decision making and subjects that affect our lives. Hence I feel that we are not taught enough about this, and that we would greatly benefit from subjects or courses related to these aspects, as well as soft skills essential to any engineer. I think all of this because to properly be able to achieve sustainability and any dream or ambition, I think we need to be more conscious of the importance and relevance of these aspects. and by understanding them more it would be easier.
  2. R2: No Comment
- **Student 4 (S4): 18 Dutch**
  1. R1: I don't think it would be helpful to have one course on sustainability, though there could maybe be specific courses about it in master tracks. I think it is much more important to talk about in courses were it is relevant, like courses about aviation or space in general, there it could be helpful.
  2. R2: I don't think it's something an engineer necessarily needs to know, since they don't make those decisions but it could be something that could be offered as an elective. For those that do want to combine them.
- **Student 5 (S5): 20 Polish**
  1. R1: I'd rather be taught about sustainability as an appendix to other related courses. The topic is not relevant to all the courses.
  2. R2: Decisions made by engineers often rely on social, economic and political situation. Such topics should be taught, or at least mentioned in our studies.
- **Student 6 (S6): 19 Dutch**
  1. R1: I think that all aerospace related courses (not calculus or physics subjects) should have a sustainability parts, because how more ideas you see on different subjects how more familiar you become with sustainability and how better you get a solving the problems.
  2. R2: Yes politics is also a important topic when you want to solve problems for aerospace engineering.

- **Student 7 (S7): 19 Italian**
  1. R1: It would be much better if every course had a portion of its syllabus dedicated to how that knowledge can be implemented while keeping sustainability in mind.
  2. R2: I think it could be good for engineers to learn how to work around such aspects to aid them in their future decision-making capabilities, instead of leaving it to just field experience.
- **Student 8 (S8): 18 Dutch**
  1. R1: Sustainability should be implemented in every course where it is possible.
  2. R2: I personally often forget that there are also these other factors to take into account, so I do think it's a good idea to implement these factors in our education. However, we shouldn't be distracted from our goals just because there are still people that for example don't believe in climate change.
- **Student 9 (S9): 18 Dutch**
  1. R1: No. I don't know to what extent the urgency of the problem is being transferred to students if they only have one topic about it. Rather, continuous education should be taught of it, if it is actually such a big problem.
  2. R2: Not necessarily. Like I said before, the search to sustainability is a collective thing. The people in politics can have environmental politics as their expertise, in social science they have environmental viewpoints as their expertise as well. Tie it all together, and you have a pretty complete picture. However in reality this does not work, as people are inherently bad at working together.
- **Student 10 (S10): 18 Polish**
  1. R1: The sustainability part of the courses should be implemented across the whole duration of other courses, because apart from it being an urgent issue, it is also a lasting issue.
  2. R2: I think these need to be taught both ways. Engineers should be taught how politicians think etc., however the politicians should be also taught about how engineering solutions work, as many people (not necessarily the politicians) have no knowledge on how the technology can help improve the sustainability.
- **Student 11 (S11): 19 Spanish**
  1. R1: I would find a sustainability course very interesting and I would find it indeed very important. I would make a separate course for it as integrating it in other course would not make us grasp the idea as they would always just comment about it but never really deepen in the topic which I find more important and effective. I think other aspects like social sciences and economy is indeed important. However politics not so much as I do not feel it affects us that much.
  2. R2: No comment
- **Student 12 (S12): 19 Italian**
  1. R1: I think that every course should have a sustainability angle to it as the environment is interconnected to everything we do and in every area it is possible to do better.
  2. R2: I think it is important to have a well-rounded view of everything that is going on. For this reason I believe it is important to not only focus on the technological and practical matter but take into account all the other factors as well.
- **Student 13 (S13): 22 Dutch**
  1. R1: I think one course should suffice and perhaps small elements throughout other courses. I think it depends a lot on the type of person is taking the course.
  2. R2: No. I think that anyone who is interested in these fields will learn about them either by themselves or through experience.

- **Student 14 (S14): 18 Dutch**
    1. R1: Every course should have a small part which looks at sustainability. otherwise you will neglect it way sooner.
    2. R2: Only to those who want to do something in that field. For instance someone who has its own company will need some understanding of economics. However when you only work FOR a company, you might not need that.
- **Student 15 (S15): 20 Japanese**
    1. R1: A single course on sustainability will not be enough for all engineers to solve the global issue of climate change. However it will increase our awareness of the issue, and that will contribute to our thought process in our future engineering designs. It is necessary to reinforce this angle of thinking at every chance possible.
    2. R2: As engineers, we are powerless to work against entire governments. Similarly to climate change, this can pose as an issue we must work around. It would be useful if the basics of these problem solving skills are taught to us in the beginning.
- **Student 16 (S16): 19 Moroccan**
    1. R1: I think that every course should have a sustainability angle, otherwise the urgency of the problem would not be understood completely. If it were missing, one could assume that there is no way to improve the sustainability in that area.
    2. R2: Yes, I do believe that the more knowledge one carrier, the more one can understand the situation and be able to change things and come up with solutions.
- **Student 17 (S17): 19 Dutch**
    1. R1: Each course can set aside a little time to learn how those topics can be applied to sustainability.
    2. R2: Yes, engineers could have the best ideas but if there is no support or no money to implement that idea it is kind of useless.
- **Student 18 (S18): 19 Portuguese**
    1. R1: No it has to be included in most courses of the degree, of course not all, but one isn't enough as there are many faces to it.
    2. R2: No, engineers are aware of this too by themselves.
- **Student 19 (S19): 18 Burkinese**
    1. R1: No, sustainability should be implemented everywhere so it becomes 'second nature', just like it's obvious for most of us to pick the cheapest options. Climate change is too urgent.
    2. R2: Yes, of course, engineers should definitely take into account every factor possible, but not every factor should be as important when picking the final design.
- **Student 20 (S20): 18 Dutch**
    1. R1: Honestly, at the moment the sustainability part at our faculty is under developed in my opinion. We look at it from a financial way: the client needs to meet a certain cost requirement, but also wants to be sustainable. We do as little as possible about sustainability to keep it cheap. Sustainability costs money and maybe we should focus more on how to make sustainability attractive on the market.
    2. R2: I do think we should keep some things separate, as social aspects, otherwise things will get to complex.
- **Student 21 (S21): 20 Austrian**
    1. R1: Every single course should incorporate the topic of sustainability ,because this is the future of aerospace (at least for our generation).
    2. R2: Yes it is easy to forget the world around us when studying or practicing engineering. So I believe it would be a good idea to incorporate political knowledge and so on.

D.5. Scepticism (M5)

- **Student 1 (S1): 19 Luxembougerish**
    1. R1: I believe it's real and not talked about enough. Scientists have continuously call upon climate emergency and it is ignored for profit.
    2. R2: I believe with our best efforts it can. However I don't see everyone putting in their best effort so that is more my fear.
    3. R3: It is obvious one solution does not exist, the progress needs to go step by step. For example, short distance planes could. be investigated first.
- **Student 2 (S2): 18 Dutch**
    1. R1: Yes I believe it is very real and in fact being downplayed by the older people who enjoyed fossil fuels and will barely witness any serious climate change effect in their lifetimes and by lobbyists/companies who are still getting rich from it
    2. R2: Yes, with best efforts we can, but I fear that the people with power and money to fund these efforts will not fully commit, slowing the climate goals down
    3. R3: If we manage to get the pollution down to acceptable level we can continue.
- **Student 3 (S3): 19 Spanish**
    1. R1: I think almost everybody agrees that climate change is real, since we can easily see the effect it has in our lives, for example the weather or the seasons are all affected. as well as the melting of the poles.
    2. R2: I believe that our current efforts will probably lead to a considerable reduction of our carbon footprint and pollution, but that it will probably not be enough on the long term. Hence we will need to do more. I believe that in certain parts of the world, where living conditions are much worse, sustainability becomes a much lesser and secondary problem, since they have more important and vital things to worry about.
    3. R3: No Comment
- **Student 4 (S4): 18 Dutch**
    1. R1: I do belie it exists and that it is a great problem for our generation and those to come.
    2. R2: I think it is very feasible to obtain the goals we have set, and even more ambitious ones. I think it is a problem of wanting to rather than being to able to achieve the goals to stop climate change.
    3. R3: Though I do believe aviation will still exist in the future, I do believe the industry has to change and its role in the world. Like for example people shouldn't fly within Europe to get to a destination, but maybe take the train.
- **Student 5 (S5): 20 Polish**
    1. R1: Studies repeatedly show the effects of climate change. I believe it is very real. Scepticism is not the same as ignorance.
    2. R2: With our "best efforts" we probably could meet the climate goals. However, I doubt that humanity will do its best about the issue.
    3. R3: If the aviation continues "as usual" and would only increase in size due to exponential growth, the industry would quickly be one of the most polluting on the planet. Continuous efforts have to be taken to ensure that we meet the climate goals.
- **Student 6 (S6): 19 Dutch**
    1. R1: Yes it is definitely real! and I think there are people who do not believe in it not only older people.
    2. R2: If we really start working now we have a change to achieve the climate goal at the end of the century, but then every one needs to work on it and not some half working people.

3. R3: No Comment

- **Student 7 (S7): 19 Italian**

    1. R1: Climate change is definitely real and it is extremely dangerous to let us be influenced by those who underestimate its potential impact.
    2. R2: We must still put our all into finding a solution to have the best chance at meeting our goals.
    3. R3: Aviation should continue towards becoming a more efficient means of transport.

- **Student 8 (S8): 18 Dutch**

    1. R1: I don't think climate change should be about believing or not. The longer time we waste thinking about whether it is true or not, the more time we lose to actually do something about it. There is however not just one solution for it. We all have to give in a bit and the sooner we react with actual measures, the smaller those measures have to be.
    2. R2: No Comment
    3. R3: No Comment

- **Student 9 (S9): 18 Dutch**

    1. R1: Yes, it is definitely not exaggerated.
    2. R2: It will be difficult. I am skeptic about peoples ability (especially in politics) to solve it, instead of laying it on the next generation.
    3. R3: Yes, but there should be looked more into sustainable ways of aviation. It is already being done, but needs to be done more effectively in order to work.

- **Student 10 (S10): 18 Polish**

    1. R1: I believe it Is and it is not being exaggerated.
    2. R2: I think it is a roulette. It depends on how well other (especially less developed countries) can adhere to the set goals. Right now I am kind of skeptical, as recycling in many parts(actually most parts) of the world is pretty much non-existent, whereas in Europe, since I was very little, the recycling has already been there.
    3. R3: Yes, with the assumption that its sustainability part is going to improve.

- **Student 11 (S11): 19 Spanish**

    1. R1: I do believe climate change is real. I believe we will be able to reduce climate change a lot however not to eradicate it or even close to eradication. I think our efforts are useful as there is not one solution to the problem however a combination of solutions are needed to reduce the problem. I hope we do meet the climate goals. I think aviation should still work in becoming more sustainable as every small solution contributes to solving the bigger problem of climate change.
    2. R2: No comment
    3. R3: No comment

- **Student 12 (S12): 19 Italian**

    1. R1: YES! I believe it is actually being played down by authorities and people in charge.
    2. R2: Yes, because the goals set are, in my opinion, pretty out of reach due to the fact that many social and political factors have not been taken into account
    3. R3: I think aviation plays a big role in connecting people, but at the same time I think the sector could be more efficient and environmentally conscious.

- **Student 13 (S13): 22 Dutch**

1. R1: No I do not believe climate change is exaggerated, if anything I think most people underplay the issue.
2. R2: I think it is highly unlikely that we will reach our climate goals, however I believe that we have a responsibility to future generations to try not matter what.
3. R3: Not sure.

- **Student 14 (S14): 18 Dutch**

1. R1: It is not exaggerated, people just don't see it as we change together with the climate change. We keep getting used to the knew situations. You also do not see yourself changing without looking at the past. Thus people must be aware of the change.
2. R2: Yes we will, in this century there will be a time when we have to do something in order to survive. When that moment comes, people will really realise the situation and find a solution.
3. R3: Yes it should, unless another way of fast and efficient transport is invented.

- **Student 15 (S15): 20 Japanese**

1. R1: There is no way to determine the gravity of climate change. Therefore, we must expect the worst and act accordingly. The issue is not whether one believes it to be true or not, but whether we will be prepared if it ends up being true. Personally, I believe it is a large issue that is not being addressed enough because it is so hard to grasp at an individual scale.
2. R2: I do not believe the entire world can be united towards one common goal, given the political turmoil and fighting that occur regularly. We will not achieve the climate goals when entire nations are uncooperative.
3. R3: Aviation is becoming increasingly less important with the development of the internet and the virtual world. With these developments, aviation may not continue as usual: I can see a world where all business is handled online, and travelling is necessary only for leisure purposes.

- **Student 16 (S16): 19 Moroccan**

1. R1: I believe that climate change is real and that it is not being exaggerated.
2. R2: I am not very optimistic about the future, since technology will continue to advance and with it the needs of all people, which will require more energy and thus more pollution.
3. R3: I think it should continue, but there should be a focus on sustainability. I believe other sectors have more impact on climate change.

- **Student 17 (S17): 19 Dutch**

1. R1: Yes it is real. No
2. R2: If everybody commits, it will be possible.
3. R3: Aviation is very efficient so its either continue as usual or stop it all together which is not really an option.

- **Student 18 (S18): 19 Portuguese**

1. R1: Yes its real.
2. R2: No, needs a lot more work than what is being done. Might be able to improve it but not fully solve it.
3. R3: Regardless of being efficient, aviation has to continue until another sustainable alternative is found since flying is essential nowadays.

- **Student 19 (S19): 18 Burkinese**

1. R1: Yes it is real. Older people care a bit less about the dangers of it.
2. R2: Nope, I think the world just isn't committed enough to meet the set goals, but there will be improvement in the coming years.

3. R3: Yes aviation should continue because it is too important in our daily lives. We've come too far to just remove it because of climate change.

- **Student 20 (S20): 18 Dutch**

1. R1: I think climate change is real and our biggest threat today. But people will always be selfish and live in the moment. Nobody is willing to suffer on his own, to maybe have the benefit later. With this i mean: financially suffer in comparison to others who still benefit from environmentally unfriendly businesses. The only solution is to strictly forbid certain actions which contribute to global warming, and with that i mean all together, everyone.
2. R2: No comment
3. R3: No comment

- **Student 21 (S21): 20 Austrian**

1. R1: Yes climate change is real. And no it is not being exaggerated, I believe it is being down played.
2. R2: I believe with our best efforts we can reach our goals.
3. R3: No aviation needs to change, needs to become more sustainable independent of if there is a single solution or not.

D.6. Temporal and Academic Value (M6)

- **Student 1 (S1): 19 Luxembougerish**

1. R1: As previously mentioned, there is no theory per say on sustainable aricraft as it does not exist yet. In our first year we are taught about existing knowledge not trying to invent new things. However, a discussion on sustainability needs to take place in more courses.
2. R2: Lecturers often skip content that cannot be graded such as sustaibility.
3. R3: No Comment

- **Student 2 (S2): 18 Dutch**

1. R1: No, I think it will be hard to fit in sustainability in each course, but I do think it is important enough to fit it in some courses, especially the design courses.
2. R2: Depends on the course, for a physics or coding course the sustainability aspect is not important enough to add in an already busy course, but for a design course I find it important enough to get graded on that aspect too and then of course also make time for it during the course.
3. R3: No not hypocritical, but self-awareness. We know aerospace is mass-pollution, but that is not our intention, so we want to reduce that pollution, to do that, we need to learn about it.

- **Student 3 (S3): 19 Spanish**

1. R1: Yes I think that sustainability is touched upon rarely, but more importantly I think that when it is talked about, it is talked in such a way that it is not very important for the course work. AS in related to the exam or actual tangible short term things, sustainability is not very important throughout the courses, and I feel students don't really pay much attention. sort of like the chapter that is not going to be asked in the exam and hence no one really pays attention to. In the project, building the beam the same., I feel that it is very secondary and "once we get the design well think about sustainability" or if it doesn't comply with sustainability its not too bad, so i think sustainability should be more important throughout the bachelor it.
2. R2: No comment
3. R3: No comment

- **Student 4 (S4): 18 Dutch**

1. R1: I do think that it would be difficult to fit an entire course on sustainability into the curriculum right now, but I do think it can be addressed in some subjects that already do exist.
2. R2: I think this depends entirely on the course and how much it is worth. If it is only something that is being said during lectures but not tested, than it is a waste of time, since people aren't going to learn it then.
3. R3: No I do not see it as hypocritical, rather I see it as an industry that need to change teaching an new generation to be able to make that change happen.

- **Student 5 (S5): 20 Polish**
  1. R1: There's has not been much coursework focused on sustainability in my program.
  2. R2: Never was I in a situation when I had to learn about sustainability get a decent grade in a course. Its either not mentioned at all or pushed aside.
  3. R3: No, it is possible for the industry to become more "green", teaching about sustainability is an important aspect of that transition.
- **Student 6 (S6): 19 Dutch**
  1. R1: There can't be too much sustainability in a course because it is the future of aerospace engineering.
  2. R2: No comment
  3. R3: No it is not a waste of time, I think it is really important because when we are graduated it is a important.
- **Student 7 (S7): 19 Italian**
  1. R1: I would be inclined to say that adding sustainability to the current coursework would prove to be quite overwhelming.
  2. R2: It is worthwhile to explore.
  3. R3: Teaching future aerospace engineers about sustainability is crucial especially because it is one of the most impactful sectors, as these future engineers are the ones that will be shaping it.
- **Student 8 (S8): 18 Dutch**
  1. R1: Sustainability is something that should not be put away when we "have no time for it" . It is a critical part of our study, and we hardly learn enough about it.
  2. R2: Also it is far from hypocritical to think and learn about it. The more an industry pollutes, the more they have to adapt to climate change by reducing pollution(after all a 10% reduction of an industry means more if that industry has
  3. R3: No Comment
- **Student 9 (S9): 18 Dutch**
  1. R1: I don't exactly know what is to come in the rest of the bachelor, but until now some aspects of the courses have been dedicated to sustainability. That said, I do not think it is ever too much.
  2. R2: Not really. This project is the first course where sustainability plays a substantial role in the final grade.
  3. R3: No, one can never have enough knowledge about sustainability, no matter their work sector.
- **Student 10 (S10): 18 Polish**
  1. R1: There is not.
  2. R2: No. the sustainability should count for a larger part of the grade, and should be given much more time. It takes too much time for the small part of the grade it usually gives.

3. R3: I don't think that, as I said earlier there is much room for improvement, which is probably the best in which the issue can be resolved.

- **Student 11 (S11): 19 Spanish**
    1. R1: I do think that subjects are very dense and incorporating sustainability would be difficult as we do not have much free time to accommodate more work, however maybe in the second year there is more time to address this topic. I do think it is an important topic to teach and I would try to make a course or try to maybe incorporate it into project as it is would be easier to fit it in, or even a new course about it.
    2. R2: No comment
    3. R3: No comment
- **Student 12 (S12): 19 Italian**
    1. R1: No, I think there is plenty of space and I think it is really important to teach about it
    2. R2: Yes
    3. R3: I think it is extremely necessary BECAUSE it is a very polluting industry, meaning that is important to make a change.
- **Student 13 (S13): 22 Dutch**
    1. R1: One extra course could probably be added but I would have some reservations about its effectiveness due to high workloads. Perhaps just making sure that there is time to contemplate about such issues would go a very long way.
    2. R2: Some, but not much.
    3. R3: No I think its anything but hypocritical to focus on climate change as aerospace engineers.
- **Student 14 (S14): 18 Dutch**
    1. R1: Yes there is, if they decide to also put sustainability in the program, people will just try to pass it and not really understand it as there just is not enough time to study.
    2. R2: As said before, you have to give up a certain part of the course in order to implement sustainability. AE already is one of the busiest technical studies in the world.
    3. R3: It never is a waste of time, just realise that when the workload is too high, people will not try to understand it, but just pass the course.
- **Student 15 (S15): 20 Japanese**
    1. R1: I believe there is some space to incorporate sustainability in some courses, maybe not all.
    2. R2: As stated in the previous answer, maybe for several courses where sustainability is more prominently affected.
    3. R3: No, teaching students about sustainability will change these "tools of 'mass pollution'" into efficient, Earth friendly travelling options.
- **Student 16 (S16): 19 Moroccan**
    1. R1: I think there isn't enough sustainability and that it's importance should be more talked about in the different courses.
    2. R2: I believe there is always time to address sustainability.
    3. R3: I don't think it is hypocritical, as it shows the desire of wanting to change things and improve the current situation.
- **Student 17 (S17): 19 Dutch**

1. R1: Depends on the course
2. R2: There is always time but it depends on the student.
3. R3: Its not a waste of time and since we are developing tools of 'mass-pollution' its useful to know how to improve.

- **Student 18 (S18): 19 Portuguese**
  1. R1: Not too much
  2. R2: Not really, its more important to grasp the actual engineering concepts.
  3. R3: Its not a waste of time neither hypocritical since its an issue for everyone.
- **Student 19 (S19): 18 Burkinese**
  1. R1: No, just a little bit in every course could already help a lot.
  2. R2: No Comment
  3. R3: No, because the new aerospace engineers have the power to stop aviation from being 'mass pollution'.
- **Student 20 (S20): 18 Dutch**
  1. R1: I think sustainability is not something you can grade, so this is not possible. Also, grading sustainability might force it too much and the whole goal of it is gone. It is more about the way of thinking. For instance, they could only shows us companies that find sustainability important, and ignore environmentally unfriendly companies. But i think that our generation already has sustainability on their minds, because we grew up with it.
  2. R2: No comment
  3. R3: No comment
- **Student 21 (S21): 20 Austrian**
  1. R1: I believe there is place for sustainability in the courses, but not in my python game. There is time.
  2. R2: No it's not hypocritical it is the right thing to doe. Like i have previously stated the future topics of aerospace are all based around sustainability. So it is no waste.
  3. R3: No comment

E

Workshop 2: Outline

Greenwashing and SDGs

E.1. Disclaimer

Not graded and ask students to be brutally honest for improvement of education and better future course structure. Use the help of Green team TA (Kiva)

E.2. Reflective Question

Begin with Workshop 1 question.

- Discuss open ended issues like economy, style of living, unreasonable number of people who have flown ever, tax leniency of aviation.
- Hope to receive multiple views on the question, and short debate the contrasting views.

E.3. Video 1

Greenwashing: A Fiji Water Story

- Discuss the areas where this is seen and understand students competence in identifying the issue in their day-to day life.
- Tangent into selective sustainability and start with researcher's own problems (Candles and Meat)
- Can this be justified? Elucidate.

E.4. Reflection: Mindset Change

Give time for students to reflect in their own life and bring about ideas which can help change/cure the mindset.

E.5. Video 2

Sustainability in action - KLM

- Talk about the recent headlines which the Dutch airline is finding itself in due to green washing concerns.
- Instruct students to look at critical things when making informed decisions and try to take that mindset forward with their design in this course.
- Ask them if they are concerned about their own profession as aviation in the future.

E.6. Video 3

Honest Government Ad | Carbon Capture & Storage

- Disclaimer: Video is meant to educate and not point fingers.

E.7. Sustainability Development Goals (SDGS)

- - Bring out the UN's outcome and the easiest way to focus on sustainability.
- Ask the students what they think are the easiest one's we can bring about today.
- Make them identify which of the 17 goals are used directly in AE2111-I (2 goals)
- Bring out examples of selective sustainability and the issue with business as usual.

E.8. Final Question

For reflection: "Can we, as a human race give up arms and war as a whole? Looking at the current situation of war in Europe, is it feasible in the near future that we can give up our militaries for the common good of humanity? As this is a strong and extremely effective means to cut emissions, is this a reasonable step to save the planet?"

P.S: This helps to solve the ethics assignment they are also given in this course.

F

Workshop 3

War, Life-Cycle Analysis and Flight Shaming

F.1. Disclaimer

Not graded and ask students to be brutally honest for improvement of education and better future course structure. Use the help of Green team TA (Kiva)

F.2. Reflective Question

Begin with Workshop 2 question.

- - Discuss the possibility of a world without borders, flags and divisions. Can we find ourselves taking responsibility for our actions of war and will there be a change in policy?
- Hope to get good contrasting views on the topic. Maintain strict a-political discussion.
- Introspect the economic, civil and status-quo nature of war as well.

F.3. Video 1

Environmental impacts of the Russia-Ukraine conflict

- Revisit the impact of war and bring out interesting takes on the quantification of the impact. US Military as an example.
- Could we look at alternate scenarios where we have to wage war as a human race against an alien race?
- Can we stick to war in our video games (Halo: Combat Evolved)

F.4. Reflection: Transport in 2050

- Provide time for reflection and subtly introduce what travelling might mean in the future.
- What would the landscape of travel and mobility look like in the future.
- Would the divide between rich and poor be seen a lot more than it is now?

F.5. Video 2

’Flight shame’: How avoiding planes might save the planet

- - Speak about the various means by which travel is possible.
- Raise the question on the perceived views of Flygskam and how they individually think about it. Represent your own shame factor.

- Is the long time taken for travel sustainable?
- Make sure that nobody points fingers due to the lingering summer holidays and opportunities for flying which are close at hand.

F.6. Video 3

Life-cycle Analyses (LCA)

- Talk about the importance of LCA in an Aerospace Engineer's life.
- Stress the individuality of a LCA and make clear the proceedings in the video are very case-specific.
- Add the underlying message of personal LCA in all the phases of lifestyle choices and in the career.

F.7. Final Take and Wrap Up

Thank all the participants for their involvement. Stress the individual perceptions of the obstacles as the fundamental driving force behind the thesis. Mention the Survey which will be sent to the student and wish them the best in their aerospace career and stress the importance of their individualism and interdisciplinary education at all levels.

G

Questionnaire Items

G.1. Demographics

1. **What is your age?**

2. **What is your gender?**

   ☐ Male
   ☐ Female
   ☐ Prefer not to say

3. **What is your nationality?**

4. **What is your AE1222-I group number?**

5. **What is your preferred aerospace domain for Master's education?**

   ☐ Aerodynamics
   ☐ Propulsion
   ☐ Structures
   ☐ Control and Simulation
   ☐ Spaceflight
   ☐ Other, please specify

6. **What is your dream aerospace career?**

   ☐ Flying aircraft (commercial pilot)
   ☐ Air Traffic Control
   ☐ Designing, building and maintaining aircraft and/or spacecraft
   ☐ Military
   ☐ Airlines and/or Airport
   ☐ Space Programs
   ☐ Academia
   ☐ Don't know
   ☐ Other, please specify

7. **Please elaborate on your dream career in a few words.**

8. **Are you aware of the negative effects of your dream career on the environment?**
   - ☐ Yes
   - ☐ No
   - ☐ Unsure

9. **I want to work for one company or organization for my whole career.**
   ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

10. **I want to work for different companies or organizations over the course of my career.**
    ☐ ☐ ☐ ☐
    Strongly disagree Strongly agree

11. **I want to work in a technical capacity for my whole career.**
    ☐ ☐ ☐ ☐
    Strongly disagree Strongly agree

12. **I want to work in a management capacity for at least half of my career.**
    ☐ ☐ ☐ ☐
    Strongly disagree Strongly agree

13. **I want to work on a different project every year.**
    ☐ ☐ ☐ ☐
    Strongly disagree Strongly agree

14. **I want to work on one project for many years.**
    ☐ ☐ ☐ ☐
    Strongly disagree Strongly agree

G.2. Interdisciplinary Education Perception Scale

1. **Individuals in my study are well trained.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

2. **Individuals in my study are able to work closely with individuals in other studies.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

3. **Individuals in my study demonstrate a great level of autonomy.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

4. **Individuals in other studies respect the work done by my study/profession.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

5. **Individuals in my study are very positive about their goals and objectives.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

6. **Individuals in my study need to cooperate with other studies/professions.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

7. **Individuals in my study are very positive about their contributions and accomplishments.**
   ☐ ☐ ☐ ☐ ☐ ☐
   Strongly disagree Strongly agree

8. **Individuals in my study must depend upon the work of people in other studies/professions.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

9. **Individuals in other studies think highly of my study.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

10. **Individuals in my study trust each other's professional judgement.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

11. **Individuals in my study have a higher status than individuals in other professions.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

12. **Individuals in my study make every effort to understand the capabilities and contributions of other studies/professions.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

13. **Individuals in my study are extremely competent.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

14. **Individuals in my study are willing to share information and resources with other professionals.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

15. **Individuals in my study have good relations with people in other studies/professions.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

16. **Individuals in my study think highly of other related professions.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

17. **Individuals in my study work well with each other.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

18. **Individuals in other studies often seek the advice of people in my study.**
☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

G.3. Interdisciplinary Skills

1. **I value reading about topics outside of engineering.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

2. **I enjoy thinking about how different fields approach the same problem in different ways.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

3. **Not all engineering problems have purely technical solutions.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

4. **In solving engineering problems I often seek information from experts in other academic fields.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

5. **Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

6. **I see connections between ideas in engineering and ideas in the humanities and social sciences.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

7. **I can take ideas from outside engineering and synthesize them in ways to better understand a problem.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

8. **I can use what I have learned in one field in another setting or to solve a new problem.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

G.4. Sustainability Scepticism: Climate

1. **Which of the following three statements do you personally believe?**

   ☐ Climate change is happening now, caused mainly by human activities.
   ☐ Climate change is happening now, but caused mainly by natural forces.
   ☐ Climate change is not happening now.
   ☐ Don't know/no answer

2. **The consequences of climate change will be very serious.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

3. **A university should have a climate change policy.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

4. **A university should contribute in its operation to achieve the carbon reduction targets set by the government.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

5. **A university should contribute in its operation to achieve the adaptation strategies to climate change set by the government.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

6. **A university should educate its students about the cause of climate change.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

7. **A university should educate its students about the impact of climate change in all disciplines.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

8. **A university should encourage its students to search for solutions with regards to problems caused by climate change.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

9. **Your University attaches a lot of importance to matters related to climate change.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

10. **The official policy or planning framework for combating climate change at your University is well developed.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

11. **The person in charge of planning on matters related to climate change issues at your university is afforded enough resources to work effectively.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

12. **Climate change policies, procedures or activities are properly implemented in teaching and research at your University.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

13. **My university contributes in its operation to achieve the carbon reduction targets set by the government.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

14. **My university educates its students about the impact of climate change on the discipline chosen by the student.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

15. **There are specific units that address climate change through 'Education for Sustainable Development' at my University.**
☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

G.5. Sustainability Scepticism: Effectiveness

1. **Most environmental claims made by aerospace firms on their advertising and social media are true.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

2. **I am sceptical about the accuracy of the environmental claims made by aerospace firms in their advertising.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

3. **Most environmental claims are to provide consumers with useful information for making choices.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

4. **Most environmental claims are to provide consumers with useful information for making choices.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

5. **Because environmental claims are often exaggerated, consumers would be better off if such claims were eliminated.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

6. **The only environmental claims I believe in are the ones I can verify.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

7. **Most environmental claims are intended to mislead rather than inform consumers.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

8. **I don't believe environmental claims in aerospace advertising until the manufacturers provide evidence that the claims are true.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

9. **Environmental claims in advertising lead people to believe things that aren't true.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

10. **I do not believe most environmental claims in aerospace firms' advertising.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

11. **Environmental claims made in advertising are generally truthful.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

12. **Environmental claims made in advertising should be more closely regulated.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

13. **Most aerospace firms avoid their responsibility to the consumer.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

14. **Most aerospace firms are more interested in making profits than in protecting the environment.**
☐ ☐ ☐ ☐ ☐ ☐ ☐
Strongly disagree Strongly agree

H Qualitative Data

This appendix provides the anonymized data of the students which was collected form the various workshops and questionnaire items. The data is posted after consent from the students.

Table H.1: Dream Aerospace Career-2

Sl. No.	Nationality	AE1222-I Group Number	Brief Description of Aerospace Career
17	Dutch	E01H	Structures, Control and Simulation, Spaceflight
18	Croatian	E09F	Aerodynamics, Control and Simulation
19	Spanish	E09G	Aerodynamics, Propulsion
20	Dutch	E01F	Spaceflight
21	Greek	E04F	Propulsion, Structures, Control and Simulation, Spaceflight
22	Dutch	E05H	Control and Simulation
23	Dutch	E09F	Control and Simulation
24	German	E08G	No clue yet
25	Czech	E05F	Aerodynamics
26	Portuguese	E08H	Aerodynamics, Spaceflight
27	Austrian	E03F	Aerodynamics, Propulsion
28	Polish	E01E	Aerodynamics, Propulsion
29	Polish	E05E	Aerodynamics, Spaceflight
30	Italian	E05E	Not sure
31	Hungarian	E05E	Propulsion
32	Romanian	E10E	Propulsion, Spaceflight

Table H.2: Dream Aerospace Career

Sl. No.	Nationality	AE1222-I Group Number	What is your dream aerospace career?
1	Italy	E04E	Flying aircraft (commercial pilot), Designing, building and maintaining aircraft and/or spacecraft, Military, Airlines and/or Airport
2	Belgian	E04F	Designing, building and maintaining aircraft and/or spacecraft
3	Dutch	E06H	Designing, building and maintaining aircraft and/or spacecraft
4	Luxembourgish	E01E	Space Programs
5	Indian	E03E	Designing, building and maintaining aircraft and/or spacecraft, Military, Airlines and/or Airport
6	Portuguese	E08F	Designing, building and maintaining aircraft and/or spacecraft
7	Romanian	E10C	Designing, building and maintaining aircraft and/or spacecraft, Academia, Infrastructure Policy and Management
8	Italian	E07E	Designing, building and maintaining aircraft and/or spacecraft, Military, Space Programs, Academia
9	Bulgarian	E07F	Airlines and/or Airport
10	Polish	E01G	Flying aircraft (commercial pilot), Designing, building and maintaining aircraft and/or spacecraft
11	Romania	E06H	Designing, building and maintaining aircraft and/or spacecraft, Space Programs
12	Chinese	E02E	Designing, building and maintaining aircraft and/or spacecraft, Academia, Automotive engineer
13	Italian	E01E	Designing, building and maintaining aircraft and/or spacecraft, Space Programs
14	Spanish	E01E	Space Programs, Don't know
15	Netherlands	E01E	Designing, building and maintaining aircraft and/or spacecraft
16	Irish and Belgian	E03E	Flying aircraft (commercial pilot), Designing, building and maintaining aircraft and/or spacecraft

Table H.3: Description of Aerospace Career

Sl. No.	Nationality	AE1222-I Group Number	Brief Description of Aerospace Career
1	Italy	E04E	Mostly military aircraft, cuz they have a huge budget, and develop really advanced stuff. Peak engineering in my opinion. And they are not always used in an offensive manner. Every country needs a defence.
2	Belgian	E04F	RD of innovative and sustainable propulsion systems
3	Dutch	E06H	I'd like to help design spaceships that are capable of bringing humans to Mars/other extraterrestrial bodies
4	Luxembourgish	E01E	I would like to work in the space business to innovate things like space mining or lunar bases.
5	Indian	E03E	I want to help in making aviation a sustainable industry while keeping it affordable for all.
6	Portuguese	E08F	-
7	Romanian	E10C	I want to participate in real, profound change in my home country of Romania.
8	Italian	E07E	I would like to start, right after graduating with my Master's, in a technical position related to whatever I had been studying. After a few years there, with a strong technical background and experience in aerospace, pursue a more managerial career maybe by means of an MBA even
9	Bulgarian	E07F	Optimizing air transport and the parties involved for more sustainable operations
10	Polish	E01G	I'm more interested in aircraft and I'd like to have a job connected to them
11	Romania	E06H	I want a career that can make a visible change in the world and from which I can be happy doing 3D modelling and testing
12	Chinese	E02E	I want to do combine my study with something creative and environmental-friendly related.
13	Italian	E01E	The design optimization of aircraft and spacecrafts is an ever-evolving field that aims to maximize the efficiency of the vehicle, while space programs allow us to monitor and gather data from space.
14	Spanish	E01E	Innovation
15	Netherlands	E01E	I would like to work on design (sub)systems including wings and control surfaces of (commercial) airplanes
16	Irish and Belgian	E03E	My dream is to be a part of a research and development team to create sustainable aircraft. I am a plane spotter so I very much appreciate the workings of flight and the engineering of aircraft but I really want to be apart of making it sustainable as it will be a issue with growing passenger numbers regardless of how efficient aircraft are becoming.

Table H.4: Description of Aerospace Career-2

Sl. No.	Nationality	AE1222-I Group Number	Brief Description of Aerospace Career
17	Dutch	E01H	I don't know yet what I precisely want
18	Croatian	E09F	I admire planes and I would want to be a part of the whole process of developing and operating planes
19	Spanish	E09G	Creating an aerospace company to compete in the private aircraft market (if the possible the commercial industry well), innovating in design in order to make aviation cheaper, sustainable and easier to reach.
20	Dutch	E01F	-
21	Greek	E04F	Nothing specific yet
22	Dutch	E05H	I would love to design planes, I don't really care whether they are military or not, although I would prefer to be with a big company like Boeing, Airbus or Lockheed Martin.
23	Dutch	E09F	Would be cool to design aircraft
24	German	E08G	Ideally, I will live in the woods with some goats and sheep and have a large vegetable garden entirely off the grid with no reliance on infrastructure. Realistically I will be a corporate sellout.
25	Czech	E05F	I would like to pursue a career as an Aerodynamics Engineer in the aerospace or automotive industries.
26	Portuguese	E08H	Astronaut or aerodynamicist
27	Austrian	E03F	I would enjoy designing, building and testing cutting-edge, sustainable propulsion technology for aircraft and spacecraft, as well as doing aerodynamics for said vehicles.
28	Polish	E01E	I'd like to work in proximity to aircraft; preferably military ones.
29	Polish	E05E	Probably according to my area of interest, but it depends on life opportunities
30	Italian	E05E	Still open to change ideas.
31	Hungarian	E05E	Create value in an innovative way in the field of engineering
32	Romanian	E10E	I want to work on something that pushes boundaries

Quantitative Data

I.1. IEPS

Table I.1: IEPS Individual Reliability

	If item dropped		
Item	**Cronbach's α**	**Mean**	**SD**
i1	0.784	4.813	0.896
i2	0.796	4.500	1.016
i3	0.799	4.688	1.030
i4	0.791	5.000	0.984
i5	0.792	4.844	0.847
i6	0.800	5.063	1.014
i7	0.797	4.906	0.689
i8	0.808	3.813	1.203
i9	0.797	5.125	0.907
i10	0.799	4.969	0.595
i11	0.814	3.500	1.244
i12	0.800	3.750	0.880
i13	0.786	4.375	0.976
i14	0.791	4.938	0.759
i15	0.789	4.563	0.914
i16	0.783	4.094	1.088
i17	0.798	4.969	0.695
i18	0.797	3.969	1.031

Table I.2: Reliability: IEPS

Estimate	**Cronbach's α**
Point estimate	0.803
95% CI lower bound	0.676
95% CI upper bound	0.888

I.2. Interdisciplinary Skills

Table I.3: Interdisciplinary Skills Individual Reliability

Item	If item dropped Cronbach's α	Mean	SD
i1	0.727	4.063	0.982
i2	0.742	3.188	0.859
i3	0.633	4	0.762
i4	0.593	3.5	1.218
i5	0.686	3.813	0.821
i6	0.648	4.25	0.718

Table I.4: Reliability: Interdisciplinary Skills

Estimate	Cronbach's α
Point estimate	0.716
95% CI lower bound	0.528
95% CI upper bound	0.839

I.3. Climate Change Scepticism

Table I.5: Climate Change Scepticism Individual Reliability

	If item dropped		
Item	**Cronbach's α**	**Mean**	**SD**
i1	0.810	4.781	0.420
i2	0.826	3.313	0.592
i3	0.810	4.844	0.369
i4	0.809	4.781	0.420
i5	0.811	4.594	0.712
i6	0.817	4.438	0.801
i7	0.811	4.625	0.609
i8	0.786	4.063	0.878
i9	0.781	3.563	0.878
i10	0.785	3.500	0.916
i11	0.762	3.344	1.153
i12	0.784	3.906	0.856
i13	0.797	3.563	1.134
i14	0.778	3.375	1.129

Table I.6: Reliability: Climate Change Scepticism

Estimate	Cronbach's α
Point estimate	0.811
95% CI lower bound	0.707
95% CI upper bound	0.886

I.4. Effectiveness Scepticism

Table I.7: Effectiveness Scepticism Individual Reliability

Item	If item dropped Cronbach's α	Mean	SD
i1	0.86	3.438	1.294
i2	0.855	5.156	1.347
i3	0.871	3.531	1.459
i4	0.892	4.906	1.51
i5	0.88	5.063	1.48
i6	0.872	4.438	1.48
i7	0.87	5.125	1.129
i8	0.866	4.875	1.431
i9	0.866	4.156	1.247
i10	0.869	2.938	1.318
i11	0.86	6.094	1.254
i12	0.873	4.75	1.32
i13	0.871	5.719	1.326

Table I.8: Reliability: Effectiveness Scepticism

Estimate	Cronbach's α
Point estimate	0.879
95% CI lower bound	0.799
95% CI upper bound	0.931

I.5. Environmental Responsibility

Table I.9: Environmental Responsibility Individual Reliability

	If item dropped		
Item	**Cronbach's α**	**Mean**	**SD**
i1	0.634	3.938	1.045
i2	0.651	2.969	0.897
i3	0.648	3.625	0.751
i4	0.634	2.75	1.136
i5	0.652	2.188	0.896
i6	0.633	4.438	0.619
i7	0.636	3.219	1.157
i8	0.616	3.313	0.78
i9	0.638	3.125	0.907
i10	0.604	3.938	0.84
i11	0.626	3.563	0.948
i12	0.65	2.063	0.914
i13	0.653	4.344	1.004
i14	0.618	4.313	0.965
i15	0.641	4.563	0.504
i16	0.616	3.281	0.729
i17	0.594	3.906	0.893
i18	0.59	3.719	0.813
i19	0.593	3.969	0.782
i20	0.592	3.906	0.777

Table I.10: Reliability: Environmental Responsibility

Estimate	Cronbach's α
Point estimate	0.639
95% CI lower bound	0.408
95% CI upper bound	0.893

I.6. Career Goals

Table I.11: Career Goals Individual Reliability

	If item dropped		
Item	**Cronbach's α**	**Mean**	**SD**
i1	0.614	1.938	0.619
i2	0.645	1.75	0.762
i3	0.606	2.719	1.054
i4	0.552	2.438	0.948
i5	0.721	2.375	0.609
i6	0.68	2.594	0.756

Table I.12: Reliability: Career Goals

Estimate	Cronbach's α
Point estimate	0.685
95% CI lower bound	0.487
95% CI upper bound	0.818

J

LDE Centre for Sustainability

J.1. KICK-OFF: YOUNG LEADERS IN SUSTAINABILITY TRANSITIONS

This kick off session was conducted on the 9th of February, 2022 at Leiden University. The Interdisciplinary Thesis Labs (ITL) were all invited to start their master thesis program on this day and it was headlined by extremely informative talks about sustainability and how this way of life could be incorporated into a career. We had a round table discussion amongst three

We got our roles defined and divided among the following topics:

- **ROOSA JOENSUU:** Circular solutions for critical raw materials in electric aviation, End-of-Life Recycling Input Rate in the supply risk of critical raw materials
- **VICTOR HUPE:** The best solution to reducing the amount of CO_2 emissions in aviation is not to fly. How can the mindset towards flying be changed to reduce flying (and therefore the CO2 emissions)?
- **THOMAS ARBLASTER:** Quantifying the trade-off between light-weighting (saving fuel) and circularization (facilitate circular strategies: reuse, refurbish, recycle, …). I.e., when does it make sense to circularize a component at the expense of its mass?
- **MARIA PAPAVASILEIOU:** Life Cycle Assessment of in-flight services and circular in-flight service practices. Can existing sustainable practices enable circularity in the aviation industry? What is the best way to improve the environmental impact of in-flight services by applying circular economy principles?
- **ELENA PETERS:** Life Cycle Assessment of additive manufacturing technology for composite structures; Life Cycle Assessment to increase focus on circularity of the technology and the technology maturity (technology readiness level)
- **PIETER-JELLE NIJDAM:** How do the existing procurement practices at Schiphol Airport influence a development towards Circular Public Procurement?
- **ALEXIS FREYTAG VON LORINGHOVEN:** the potential of the circular economy for net-zero emission aviation.
- **ANTONY JOSEPH VALIAVEETIL:** Sustainability in Education: Looking for obstacles and barriers within aerospace education which prevent incorporation of sustainable practices within students who represent the future aviation industry.

J.2. IN DEPTH LECTURE:ENVIRONMENTAL CHANGE

This session was a thought provoking lecture given by **Prof Paul Behrens from Leiden University on the 24/02/2022.**

In this presentation, we were guided through the huge task of cutting emissions. This was followed by a reminder of the uncertain future this planet and society is about to face. Then the narrative was shifted to impacts of climate change and the ‘brace yourself’ attitude that is needed from us all.

The time for change is short, hence , every action can be of immense use for the bigger picture. Electrification of every form of technology is needed and this should be run on Renewable Energy.

Food transition is also necessary and to propagate this awareness with he help of the media is a effective way to move forward.

The simple steps which an individual can take is also mentioned and communication is key to every problem.

J.3. IN-DEPTH LECTURE:CRITICAL RAW MATERIALS IN THE AVIATION INDUSTRY

This session was a thought provoking lecture given by **Prof David Peck from TU Delft on the 10/03/2022.**

In this presentation, the criticality of Gold was discussed and the question of how economical a material is was discussed. The circularity involved in Life Extension was also mentioned. The EU method of Critical Raw Materials (CRM) classification was spoken about.

The sourcing of these materials and the recycling rate were also mentioned. Steel, Aluminium and critical alloys in cities were mentioned.

The opportunities which aviation possesses were put forward and this was a good talk about lean manufacturing and the current war in Russia and Ukraine.

Finally the CRM course provided by TU Delft was recommended.

J.4. IN-DEPTH LECTURE: EOL OF THE AIRCRAFT

This session was a thought provoking lecture given by **Derk-Jan van Heerden from Aircraft End-of-Life Solutions (AELS) on the 23/03/2022.**

After a brief introduction, the end of a Boeing 747 was discussed from the runway of Twente Airport. But is this the end? or is there a new beginning?

The nubers of retired aircraft have been increasing from 2004 to 2019 (almost 36.2%). the entire supply chain of AELS was mentioned and the various problems they face was briefly touched upon. After the overview, the decision to choose an EOL path was brought forward.

Disassembly, Dismantling and Material Recycling and AELS thoughts on this was discussed. The innovations and challenges of AELS in today’s economic driven world were presented and this ended with the possibility of being recruited by AELS.

J.5. IN-DEPTH LECTURE: POLICY IN SUSTAINABLE AVIATION

This session was a thought provoking lecture given by **Prof Steven Truxal from Leiden University on the 07/04/2022.**

In this presentation, the difference between the governments (State) and the markets were pointed out. Another important aspect was the economic or environmental path that needs to be followed. The aviation ecosystem and the solutions to the legal obstacles was mentioned and discussed.

UNFCCC, ICAO and CORSIA along with the significance to the EU Treaties was very thoroughly explained. European Climate Law and cap & trade systems in the EU were presented. Carbon markets and competition law was presented and the issues with war and the current situation was mentioned.

Environmental tax and Carbon process were presented with the greenwashing paradigm.

J.6. ROUND TABLE

CIRCULAR AVIATION - 21/04/2022

Dear round table guests, please find the questions for the event below. Due to the relatively short amount of time and high number of students we prioritised the questions into main questions and back-up questions (that will be used if there is time left). Additionally, we would like to ask you to keep your answers to the questions under 5 minutes. The event and questions will divided into three main topics of interest. Each section starts with a short starting statement, followed by the questions. Many thanks for your time and participation in the round table. We are looking forward to an interesting discussion!

J.7. Opening Questions

1. How is your organization currently working towards sustainable, circular aviation?

2. Statements on what the future of aviation looks like? (in regards to circularity)

J.7.1. Operations - Customer perspective, Inflight, Airports and Education

Can the aviation industry operate more sustainably or are these two too contradicting? Sustainable and circular methods can be introduced to a sector at various stages: at the design level, in operations and at the end-of-life. Here we focus on how to implement these methods in the aviation sector, and if that is possible in the first place.

Main questions:

- What are the sustainability challenges and pitfalls you faced in the industry which you wished was taught to you during your study life?

- The most sustainable solution for flying is not to fly. To what extent do you think that is possible (for consumer flights or/and business flights)?

- Could circularity become a mandatory part of the airline operations/service, and how would you envision that?

Backup/Extra questions:

- In their effort to embrace sustainability and become more competitive in the market, airlines might fall into the trap of greenwashing. Are there established ways to verify the circular practices of an airline and how can customers identify greenwashing?

- Are product life extension and recycling strategies enough to reduce the inflight service impact on the environment? Would redesign of the whole service experience be necessary to see a significant reduction?

- To what extent do you think meetings in virtual meeting rooms with vr goggles will impact the amount of business flights (because currently with the possibility to use zoom doesn't seem to really make an impact https://www.oag.com/coronavirus-airline-schedules-data)?

- Why do you think that are people still flying when they have an alternative (online meeting)?

J.7.2. Electrification - Materials for electrification

Electrification of aircraft systems and novel propulsion systems from batteries to hydrogen promise to reduce the emissions of future fleets. However, components used in electric aircraft, especially in the case of battery-electric aircraft, contain materials that are considered critical in the EU. Such materials are for example lithium and cobalt used in batteries and Rare Earth Elements used in electric motors. Critical raw materials are defined as materials with high economic importance and supply risk.

Main questions:

- How feasible are these novel propulsion solutions now, and what role will they play in the coming decades?
- What kind of challenges could the use of critical raw materials in batteries and electric motors pose for the aviation industry, if any?
- Sourcing of critical raw materials is also associated with many social issues and human rights violations. How are these considered in the supply chains now and how should these be addressed in the future?

Backup/Extra questions:

- To reduce the supply risks, component end-of-life reuse and recycling could contribute to the material supplies. Do you see possibilities for battery and electric motor reuse and recycling in the aviation sector?

J.7.3. Structures & Materials - Composites

On the scale of an individual aircraft, technical performance is paramount in limiting emissions. In the context of aviation structures, this means lightweighting. We've gone from wood, to aluminum alloys, to composites with a high production burden and which aren't recycled.

Main questions:

- How do you view this trend? Are developments in materials bound to outpace end-of-life solutions?
- Do you see pathways to closing loops for aerospace materials? Falling back on alloys, or the right innovations to allow for recyclable composites?
- Do you think that one material is superior (in terms of performance, circularity) to the others? or what needs to be done (e.g. innovations) to make one superior?
- What role do OEMs (original equipment manufacturers) already play in circularizing their aircraft?
- How could this be increased?

J.8. WORKSHOP 'YOUNG LEADERSHIP IN SUSTAINABILITY TRANSITIONS'

This session was headlined by the competencies of sustainability (Wiek et al., 2011) and we were split into groups and played a Climate Change Game as a role-playing scenario which could make everyone understand the complexity of the situation.

J.9. Visit to NLR, Markenesse

This was a visit to NLR Markenesse, and as the researcher was suffering from COVID-19, this visit was unfortunately not made.

J.10. IN-DEPTH LECTURE: SUPPLY CHAIN RESILIENCE AND CRITICAL MATERIALS FOR AVIATION

This session was a thought provoking lecture given by **Prof Benjamin Sprecher from TU Delft and Leiden university on the 19/05/2022.**

This was started off by the premise that we need critical metals for the future of sustainable energy. The threat and criticality of the supply of raw materials was then presented. The Ukraine invasions has made things worse. So say no to war. The war also actually leads to faster energy transition and decarbonization. However, there are broader geopolitical consequences.

There is demand for 4 critical metals in the Netherlands by 2050 and China is important for all these supply chains. Hence the political scenario is very important for the sustainability transition and this includes the situation with critical metals.

Finally 4 circular strategies were presented to Rethink, Reduce, Repair and Recycle the current crop of materials and metals. For this we need strategy, opportunity and all four measures in equal quantities.

J.11. WORKSHOP 'SCIENCE COMMUNICATION'

This workshop was conducted at **Leiden University on 01/06/2022** and was extremely relevant for the presentations. here we were asked to write a one-pager about our thesis which addressed the following items:

- **Purpose:** Is it necessary to inform, persuade or collaborate?
- **Audience:** What they know (prior), why they would be interested and what are their expectations?
- **Message:** What should they take home? Can metaphors be used? Can jargon be replaced by simpler language?
- Include elements like relevance, main findings and conclusion with images and figures that support the story. All this should be structured for the best possible message.

J.12. PRESSURE COOKER OF 2 DAYS

These two days were intense sessions where we were made to use Lego to portray the issues we faced during the Thesis and come up with a common solution to the Climate Change problem which we had to address through our Circular Aviation Lab.

The images for this session are found here: Figure J.1 and Figure J.2

J.13. FINAL PRESENTATIONS

This was the final session of the Circular Aviation Lab and here we presented our common solution to the case holder, Ligeia Paletti, from NLR. The image is presented in Figure J.3. This session marked the end of the Circular Aviation lab and it was a very informative session which incited a lot of discussions ideas and the flow of insights was immense.

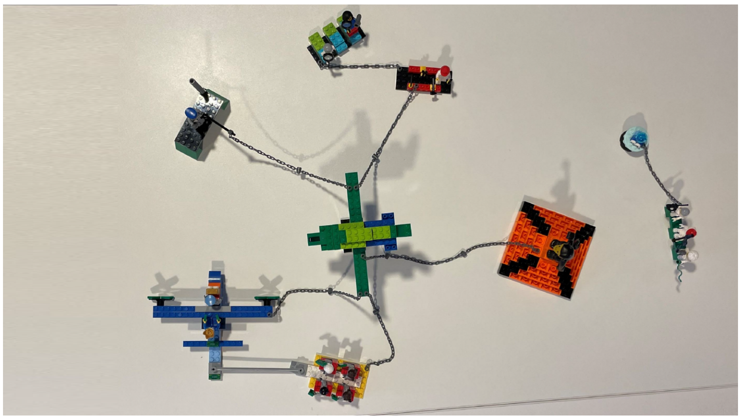


Figure J.1: Lego Representation: Circular Aviation Lab

Figure J.2: Lego Representation: Circular Aviation presentation

Figure J.3: NLR Final Presentation

Bibliography

Abd-Elwahed, M. S., & Al-Bahi, A. M. (2020). Sustainability awareness in engineering curriculum through a proposed teaching and assessment framework. *International Journal of Technology and Design Education*, *31*(3), 633–651. https://doi.org/10.1007/s10798-020-09567-0

Ackermann, Fran, Eden, & Colin. (2011). Strategic management of stakeholders: Theory and practice. *Long Range Planning*, *44*, 179–196. https://doi.org/10.1016/j.lrp.2010.08.001

Alderliesten, R., Eskue, N., & Pascoe, J.-A. (2021). Smart certification for sustainable aviation. https://www.tudelft.nl/en/stories/articles/smart-certification-for-sustainable-aviation

Anderson, T. L., & Kosnik, L.-R. (2002). Sustainable skepticism and sustainable development. *Case W. Res. L. Rev.*, *53*, 439.

Arblaster, T. P., Mandl, M. J., & Segeren, M. (2020).

Armstrong, P. (2010). Bloom's taxonomy. https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

Asana, T. (2021). Top-down approach vs. bottom-up approach: What's the difference? • asana. https://asana.com/resources/top-down-approach

Avison, D. E., Lau, F., Myers, M. D., & Nielsen, P. A. (1999). Action research. *Communications of the ACM*, *42*(1), 94–97. https://doi.org/10.1145/291469.291479

Banister, D. (2012). Transport and economic development: Reviewing the evidence. *Transport Reviews*, *32*(1), 1–2. https://doi.org/10.1080/01441647.2011.603283

Bish, J. J. (2020). Overpopulation: Cause and effect. https://www.populationmedia.org/blog/overpopulation-cause-and-effect

Bolderdijk, J. W., Steg, L., Woerdman, E., Frieswijk, R., & De Groot, J. I. (2017). Understanding effectiveness skepticism. *Journal of Public Policy and Marketing*, *36*(2), 348–361. https://doi.org/10.1509/jppm.16.118

Bolghari, M., & Hajimaghsoodi, A. (2017). Action research as a bottom-up approach to foster teacher involvement in language curriculum change. *Journal of Language Teaching and Research*, *8*, 362. https://doi.org/10.17507/jltr.0802.20

Buchko, A. A. (1994). Conceptualization and measurement of environmental uncertainty: An assessment of the miles and snow perceived environmental uncertainty scale. *Academy of Management Journal*, *37*(2), 410–425. https://doi.org/10.2307/256836

CAN and ICSA. (2018). Contribution of the global aviation sector to achieving paris agreement climate objectives. https://unfccc.int/sites/default/files/resource/156_CAN%5C%20ICSA%5C%20Aviation%5C%20TD%5C%20submission.pdf

Capdevila, I., Bruno, J., & Jofre, L. (2002). Curriculum greening and environmental research co-ordination at the technical university of catalonia, barcelona. *Journal of Cleaner Production*, *10*(1), 25–31. https://doi.org/https://doi.org/10.1016/S0959-6526(01)00019-1

Carrington, D. (2020). World's consumption of materials hits record 100bn tonnes a year. https://www.theguardian.com/environment/2020/jan/22/worlds-consumption-of-materials-hits-record-100bn-tonnes-a-year

Cho, Y.-N., & Taylor, C. R. (2020). The role of ambiguity and skepticism in the effectiveness of sustainability labeling. *Journal of Business Research*, *120*, 379–388. https://doi.org/10.1016/j.jbusres.2019.08.034

Circular Online. (2021). Cop26: To fix the climate, we must fix the economy. here's why. https://www.circularonline.co.uk/features/cop26-to-fix-the-climate-we-must-fix-the-economy-heres-why/

Conklin, J. (2005). *Educational Horizons*, *83*(3), 154–159. Retrieved August 14, 2022, from http://www.jstor.org/stable/42926529

DelftX. (2021). Sustainable aviation: The route to climate-neutral aviation. https://www.edx.org/course/sustainable-aviation

Domone, J., Bliss, P., & Copus, M. (2021). A circular economy for civil aerospace. https://doi.org/10.13140/RG.2.2.15380.01927

Eisenhauer, D. C. (2016). Pathways to climate change adaptation: Making climate change action political. *Geography Compass*, *10*(5), 207–221. https://doi.org/10.1111/gec3.12263

Ellen MacArthur Foundation. (2020). New to circular economy overview. https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Fernández-Manzanal, R., Rodríguez-Barreiro, L., & Carrasquer, J. (2007). Evaluation of environmental attitudes: Analysis and results of a scale applied to university students. *Science Education*, *91*(6), 988–1009. https://doi.org/https://doi.org/10.1002/sce.20218

Gantogtokh, O., & Quinlan, K. M. (2017). Challenges of designing interdisciplinary postgraduate curricula: Case studies of interdisciplinary master's programmes at a research-intensive uk university. *Teaching in Higher Education*, *22*(5), 569–586. https://doi.org/10.1080/13562517.2016.1273211

Genus, A., & Stirling, A. (2018). Collingridge and the dilemma of control: Towards responsible and accountable innovation. *Research Policy*, *47*(1), 61–69. https://doi.org/https://doi.org/10.1016/j.respol.2017.09.012

Het Groene Brein. (2021). How does circularity relate to sustainability? https://kenniskaarten.hetgroenebrein.nl/en/knowledge-map-circular-economy/related-schools-of-thought/

Holmberg, J., & Samuelsson, B. E. (2005). Drivers and barriers for implementing sustainable development in higher education. *Contributions to the UN Decade of Education for Sustainable Development*. https://doi.org/10.3726/978-3-653-01631-4/5

Horhota, M., Asman, J., Stratton, J., & Halfacre, A. (2014). Identifying behavioral barriers to campus sustainability: A multi-method approach. *International Journal of Sustainability in Higher Education*, *15*. https://doi.org/10.1108/IJSHE-07-2012-0065

Horvat, R. E., & Voelker, A. M. (1976). Using a likert scale to measure "environmental responsibility". *The Journal of Environmental Education*, *8*(1), 36–47. https://doi.org/10.1080/00958964.1976.9941556

Hoyle, B. S. (1973). Introduction. *Transport and development* (pp. 5–10).

Hubert, N., & Weinzierl, R. (2022). How to incorporate sustainability in your education within a short timeframe and with the right support system! https://www.tudelft.nl/teachingacademy/newsletters/the-educator-may-2022/how-to-incorporate-sustainability-in-your-education-within-a-short-timeframe-and-with-the-right-support-system

Jaeger, B., & Upadhyay, A. (2020). Understanding barriers to circular economy: Cases from the manufacturing industry. *Journal of Enterprise Information Management*, *33*(4), 729–745. https://doi.org/10.1108/jeim-02-2019-0047

Jans, L. (2021). Changing environmental behaviour from the bottom up: The formation of pro-environmental social identities. *Journal of Environmental Psychology*, *73*, 101531. https://doi.org/10.1016/j.jenvp.2020.101531

Johnston, A. (2007).

Kirchherr, J., & Piscicelli, L. (2019). Towards an education for the circular economy (ece): Five teaching principles and a case study. *Resources, Conservation and Recycling*, *150*, 104406. https://doi.org/https://doi.org/10.1016/j.resconrec.2019.104406

Klaassen, R. G. (2018). Interdisciplinary education: A case study. *European Journal of Engineering Education*, *43*(6), 842–859. https://doi.org/10.1080/03043797.2018.1442417

Klaniecki, K., Wuropulos, K., & Hager, C. (2018). Behaviour change for sustainable development. https://doi.org/10.1007/978-3-319-63951-2_161-1

Kopnina, H. (2018). Teaching circular economy: Overcoming the challenge of green-washing. https://doi.org/10.1007/978-3-319-71312-0_48

Lam, J. C. K., Walker, R. M., & Hills, P. (2014). Interdisciplinarity in sustainability studies: A review. *Sustainable Development*, *22*(3), 158–176. https://doi.org/https://doi.org/10.1002/sd.533

LDE. (2022). https://www.centre-for-sustainability.nl/home

LDE CFS. (2022). Interdisciplinary thesis lab: Circular aviation. https://www.centre-for-sustainability.nl/interdisciplinary-thesis-lab-circular-aviation

Leal Filho, W., Mifsud, M., Molthan-Hill, P., J. Nagy, G., Veiga Ávila, L., & Salvia, A. L. (2019). Climate change scepticism at universities: A global study. *Sustainability*, *11*(10). https://doi.org/10.3390/su11102981

Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C., Lim, L. L., Owen, B., & Sausen, R. (2009). Aviation and global climate change in the 21st century. *Atmospheric Environment*, *43*(22), 3520–3537. https://doi.org/https://doi.org/10.1016/j.atmosenv.2009.04.024

Lennane, A. (2020). As more aircraft are scrapped, 'we must aim to recycle every part of them'. https://theloadstar.com/as-more-aircraft-are-scrapped-we-must-aim-to-recycle-every-part-of-them/

Lingwood, N. (2021). Creating sustainability in a bottom up approach. https://aaltodoc.aalto.fi/bitstream/handle/123456789/107312/bachelor_Lingwood_Natalie_2021.pdf?sequence=1

Lisa R. Lattuca, D. B. K., & Bergom, I. M. (2012). Developing a measure of interdisciplinary competence for engineers [https://peer.asee.org/21173]. *2012 ASEE Annual Conference & Exposition*, (10.18260/1-2–21173).

Logsdon, J. M. (1997). The united states, the only space superpower. *Space Policy*, *13*(4), 273–277. https://doi.org/https://doi.org/10.1016/S0265-9646(97)00028-3

Loo, B. P., & Banister, D. (2016). Decoupling transport from economic growth: Extending the debate to include environmental and social externalities. *Journal of Transport Geography*, *57*, 134–144. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2016.10.006

Maiorescu, I., Sabou, G., Bucur, M., & Zota, R. D. (2020). Sustainability barriers and motivations in higher education a students perspective. *Amfiteatru Economic*, *22*, 362. https://doi.org/10.24818/EA/2020/54/362

Malik, M. N., Khan, H. H., Chofreh, A. G., Goni, F. A., Klemeš, J. J., & Alotaibi, Y. (2019). Investigating students' sustainability awareness and the curriculum of technology education in pakistan. *Sustainability*, *11*(9). https://doi.org/10.3390/su11092651

Manjengwa, E. (2020). Advantages of employing mixed methods research in impact evaluation · underhill corporate solutions. https://www.underhillsolutions.co.za/2020/08/07/advantages-of-employing-mixed-methods-research-in-impact-evaluation/

McTaggart, R. (2002). Chapter 1: Action research scholar: The role of the scholar in action research. *Counterpoints*, *183*, 1–16. Retrieved August 20, 2022, from http://www.jstor.org/stable/42976827

Meldrum, R. (2021). Circularity is new? ... but aviation has been doing it for years! https://www.linkedin.com/pulse/circularity-new-aviation-has-been-doing-years-rebecca-meldrum

Melkert, J. (2022). Stakeholders of the faculty of aerospace engineering, tu delft.

Ministerie van Infrastructuur en Waterstaat. (2021). Need for a circular economy. https://www.government.nl/topics/circular-economy/need-for-a-circular-economy

Mohr, L. A., EROLU, D., & ELLEN, P. S. (1998). The development and testing of a measure of skepticism toward environmental claims in marketers' communications. *The Journal of Consumer Affairs*, *32*(1), 30–55. Retrieved August 21, 2022, from http://www.jstor.org/stable/23859544

Moore, J. (2005). Barriers and pathways to creating sustainability education programs: Policy, rhetoric and reality. *Environmental Education Research - ENVIRON EDUC RES*, *11*, 537–555. https://doi.org/10.1080/13504620500169692

Næss, P. (2006). Unsustainable growth, unsustainable capitalism. *Journal of Critical Realism*, *5*(2), 197–227. https://doi.org/10.1558/jocr.v5i2.197

Newell, W. H., Wentworth, J., & Sebberson, D. (2001). A theory of interdisciplinary studies. *Issues in Interdisciplinary Studies*.

Nikitina, S. (2006). Three strategies for interdisciplinary teaching: Contextualizing, conceptualizing, and problemcentring. *Journal of Curriculum Studies*, *38*(3), 251–271. https://doi.org/10.1080/00220270500422632

NQA. (2010). Aerospace industry standards. https://www.nqa.com/en-us/certification/sectors/aerospace

O'Neill, B. C., Mackellar, E. L., & Lutz, W. (2002). Population and climate change. *Climate Policy*, *2*(2-3), 261–263. https://doi.org/10.1016/s1469-3062(02)00034-7

Orr, D. (2012). Energy: Curbing urban greed. *Nature*, *481*(7380), 142–143. https://doi.org/10.1038/481142a

Paletti, L. (2021). https://www.nlr.org/nlr-blog/an-addition-to-the-sustainable-development-goals/

Peter, S. C. (2018). Reduction of co2 to chemicals and fuels: A solution to global warming and energy crisis. *ACS Energy Letters*, *3*(7), 1557–1561. https://doi.org/10.1021/acsenergylett.8b00878

Pop, V. (2011). Space exploration and folk beliefs on climate change. *Astropolitics*, *9*(1), 50–62. https://doi.org/10.1080/14777622.2011.557618

Power, M. (2019). Business value in a circular economy. https://www.locusresearch.com/think/blog/2019/08/business-value-circular-economy

Rizos, V., Tuokko, K., & Behrens, A. (2017). *The Circular Economy: A review of definitions, processes and impacts* (CEPS Papers No. 12440). Centre for European Policy Studies. https://ideas.repec.org/p/eps/cepswp/12440.html

Rodrigues Dias, V. M., Jugend, D., de Camargo Fiorini, P., do Amaral Razzino, C., & Paula Pinheiro, M. A. (2022). Possibilities for applying the circular economy in the aerospace industry: Practices, opportunities and challenges. *Journal of Air Transport Management*, *102*, 102227. https://doi.org/https://doi.org/10.1016/j.jairtraman.2022.102227

Roser, M. (2013). Future population growth. https://ourworldindata.org/future-population-growth

Sarathchandra, D., & Haltinner, K. (2021). A survey instrument to measure skeptics' (dis)trust in climate science. *Climate*, *9*(2). https://doi.org/10.3390/cli9020018

Scarborough, C., & Cantarello, E. (2018). Barriers to pro-environmental behaviours at bournemouth university. *Meliora: International Journal of Student Sustainability Research*, *1*(2). https://doi.org/10.22493/meliora.1.2.0010

Schauffler, M. (2018). Air travel the 'fastest and cheapest way to fry the planet'. https://www.pressherald.com/2018/07/22/grounded-air-travel-takes-a-high-toll/

Schauss, M., & Sprenger, S. (2021). Students' conceptions of uncertainties in the context of climate change. *International Research in Geographical and Environmental Education*, *30*(4), 332–347. https://doi.org/10.1080/10382046.2020.1852782

Schilling, M. A. (2008). *Strategic management of technological innovation*. McGraw-Hill.

Schuurman, M. (2022). Ae1222-i course study guide. https://studiegids.tudelft.nl/a101_displayCourse.do?course_id=57937

Schuurman, M. J. (2021). Ae1222-i design and construction.

Sibbel, A. (2009). Pathways towards sustainability through higher education. *International Journal of Sustainability in Higher Education*, *10*(1), 68–82. https://doi.org/10.1108/14676370910925262

Smith, J. L. (2008). A critical appreciation of the "bottom-up" approach to sustainable water management: Embracing complexity rather than desirability. *Local Environment*, *13*(4), 353–366. https://doi.org/10.1080/13549830701803323

Source. (2021). A bottom-up approach to sustainability. https://www.sourceglobalresearch.com/blog-post/a-bottom-up-approach-to-sustainability

Spike Aerospace. (2017). How transportation changed the world. https://www.spikeaerospace.com/how-transportation-changed-the-world/

Stay Grounded. (2019). Degrowth of aviation. https://stay-grounded.org/report-degrowth-of-aviation/

Stefanakis, A. I. (2020). How to achieve sustainability? through circular economy! https://sustainabilitycommunity.springernature.com/posts/how-to-achieve-sustainability-through-circular-economy

Stevenson, K., Bondell, H., Moore, S., & Carrier, S. (2014). Overcoming skepticism with education: Interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. *Climatic Change*, *126*, 1–12. https://doi.org/10.1007/s10584-014-1228-7

TU Delft. (2021). Tu delft weer op plaats 57 in de qs world university ranking. https://www.tudelft.nl/2021/tu-delft/tu-delft-weer-op-plaats-57-in-de-qs-world-university-ranking

TU Delft. (2022). Sustainability at tu delft. https://www.tudelft.nl/en/sustainability/

TU Delft LR. (2022a). Irene fernandez villegas benoemd tot ae sustainability officer. https://www.tudelft.nl/2021/lr/irene-fernandez-villegas-benoemd-tot-ae-sustainability-officer

TU Delft LR. (2022b). Management team: Faculty of aerospace enginerring. https://www.tudelft.nl/lr/organisatie/managementteam

TUD Education. (2022). Tu delft education. https://www.tudelft.nl/greentu/pillars/education

TUD Online. (2018). Mooc: Circular economy: An introduction: Tu delft online. https://online-learning.tudelft.nl/courses/circular-economy-design-and-technology/

TUD Online. (2021). Mooc: Sustainable aviation - the route to climate neutral aviation: Tu delft online. https://online-learning.tudelft.nl/courses/sustainable-aviation-the-route-to-climate-neutral-aviation/

UNDESA. (2022). World population prospects - population division. https://population.un.org/wpp/

UNSD. (2022). The 17 goals | sustainable development. https://sdgs.un.org/goals
van der Niet, S., & Bruinsma, M. (2022). Ketenemissies elektriciteit - co2emissiefactoren.nl [Accessed : 2022-04-08]. https://www.co2emissiefactoren.nl/wp-content/uploads/2022/01/23-CE-Delft-Ketenemissies-elektriciteit-2022.pdf
Vaughan, B., Macfarlane, C., Dentry, T., & Mendoza, G. (2014). The interdisciplinary education perception scale (ieps): Which factor structure? *Education in Medicine Journal*, *6*. https://doi.org/10.5959/eimj.v6i3.259
Velazquez, L., Munguia, N., & Sanchez, M. (2005). Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions. *International Journal of Sustainability in Higher Education*, *6*, 383–391. https://doi.org/10.1108/14676370510623865
Verburg, R. (2020). Technology, policy and management: Mot2910 msc thesis project. https://studiegids.tudelft.nl/a101_displayCourse.do?course_id=57743
Wade, R. (2008). Education for sustainability: Challenges and opportunities. *Policy and Practice: A Development Education Review*, *6*, 30–48. https://doi.org/https://www.developmenteducationreview.com/issue/issue-6/education-sustainability-challenges-and-opportunities
Weigel, A., Uebelhart, S., & Daspit, R. (2009). Survey of student attitudes toward aerospace careers. http://web.mit.edu/caspar/sasaoverview2009.pdf
Weir, D., Neimark, B., & Belcher, O. (2021). How the world's militaries hide their huge carbon emissions. https://theconversation.com/how-the-worlds-militaries-hide-their-huge-carbon-emissions-171466
Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, *6*(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6