Learning with Astronomy: Neural Network Studies of Galaxy Evolution and Inspiring, Skill Based Learning

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A dissertation submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

of

University College London.

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University College London

March 3, 2023

I, Choong Ling Liew-Cain, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Abstract

This study focuses on two different types of learning that can be derived from astronomy: machine learning to examine galaxies and inform their evolution, and using astronomy as an inspiring vehicle to develop skills useful to underrepresented audiences.

Upcoming large-area narrow-band photometric surveys will observe a large number of galaxies efficiently. However, it will be computationally challenging to analyse the stellar populations of galaxies from such big data to investigate their formation and evolutionary histories. We have applied a convolutional neural network (CNN) technique to retrieve the metallicity and age from narrow-band data efficiently. The CNN was trained using synthetic photometry from the integral field unit spectra and the age and metallicity obtained from spectral analysis. We show that our CNN model can recover age and metallicity from narrow-band data. We also find that the diversity of the dataset for training the CNN has a significant impact on the accuracy of its predictions. Hence, future applications of CNNs require high quality spectroscopic data from a diverse population of galaxies.

This study also presents a way to use astronomy to engage with the novel audience of jobseekers to co-create a mutually beneficial method of engagement. We worked with people looking for work in the cultural sector. We ran an online survey to assess participants' interest in science and what career-relevant skills they desired. We found that many of the skills which our participants are interested in are aligned with skills needed for astronomy research. Though our participants felt disconnected from science they still maintained an interest in learning about astronomy. We also ran a co-creation session to collaboratively create a skills-focused

astronomy pilot workshop. We find three themes arising from the co-creation session, which have implications for effective engagement with audiences who feel disconnected from science.

Impact Statement

The neural network studies of galaxy evolution portion of this thesis has demonstrated the effectiveness and suitability of convolutional neural networks to analyse stellar populations in galaxies. This work is an early, pioneering example of the effective application of machine learning to stellar population studies using large-scale narrow-band filter galaxy surveys. With the release of the miniJPAS survey in 2020 and the eventual release of the full J-PAS survey, there is a large volume of data to be analysed which our proof-of-concept study in Chapter 2 demonstrates that convolutional neural networks are well suited to analyse.

I have given talks about my neural network research at conferences and collaboration meetings between different universities. As part of my outreach work during my PhD, I have presented my original research to lay audiences both online and in person. For some people, this was their first exposure to the use of machine learning in astronomy, which had a great impact on their interest in the field.

The skill-based learning part of this thesis is a venture into a new, multidisciplinary area of research. The audience I am working with is not usually targeted by public engagement schemes. Chapters 3 and 4 discusses our work with people who are looking for employment in the arts and cultural sectors and could provide a way for them to engage or re-engage with astronomy and science. This can have a large impact on the lives of the people involved and those who interact with them, as is discussed in Section 1.4.4.

Chapter 3 focuses on our work with people looking for employment in the arts and cultural sectors. However, our findings are likely applicable to other sectors which are perceived as being disengaged with science. This makes our results valu-

able for scientists looking to engage wider audiences with their research. This chapter details our use of the co-creation methodology which has not been frequently used in the physical sciences. The details of the workshop we have developed in Chapter 4 will be given to our partner organisation, A New Direction, to include in their portfolio of courses for jobseekers if they wish to use it. This way, our work to engage jobseekers with science can continue beyond the duration of my PhD.

Acknowledgements

Firstly, I'd like to thank Daisuke Kawata for supervising me for my PhD, and accepting me as another student when he was already so busy with his other students at the time. Daisuke has always been supportive of me and my career from the moment I thought about switching supervisor to now when I'm finally writing up my PhD, and he's always been kind to a fault. He has also put in so much effort to learn about ways he can support me more – and doubtless his other students – including how mental health difficulties have affected me and then about outreach and public engagement when I was losing motivation during the pandemic and wanted to change the topic of my thesis. I would not have finished the PhD without someone as caring and encouraging as Daisuke in my corner.

I would also like to thank my other supervisors: Ignacio Ferreras, Myrto Symeonidis and Ben Littlefield. I joke sometimes that I have been collecting PhD supervisors, but I really have appreciated the help each and every one of them has given me. All three of them have really helped me along at points in my PhD journey, from discussions of science, outreach and work to just having an experienced scientist to bounce ideas off of. In particular, Ben has been invaluable for my outreach work as he has such a wealth of knowledge he has shared with me and has always brought enthusiasm and positivity to all of our meetings.

The study presented in Chapter 3 was partly funded through a *Listen & Learn* grant from UCL Culture, which allowed us to reimburse the participants of our co-creation workshop and offer incentives for completing our questionnaire. Chapters 3 and 4 would not have happened without the insight and experience of Jen DeWitt and the help of A New Direction staff members, past and present. In particular,

Seung Sing Sou, Racheal Baskeyfield and Deborah Mayaki who helped us put the co-creation session together and recruit participants. I would also like to thank all of the participants who gave up their time to let us know their opinions which have been a huge part of informing where my work has gone.

After I have finished writing up this thesis, I will start working at The Ogden Trust full time. I would like to thank the staff there, particularly Adam Boal and Clare Harvey, for being so flexible and allowing me to shift my working hours when funding became a problem and so that I could finish writing over the course of a few months part time rather than having to cram everything in within the space of a couple of months with whatever effect that would have had on my mental health.

On a more personal note, I also could not have made it through four years of a PhD without Sam Brennan, my amazing partner. He has helped my carry on through the times when life has been difficult and believed in me when I didn't believe in myself. He has always been there for me, from when I started this PhD and we were in a long distance relationship, through lockdowns when he came to stay with me because I didn't want to be alone, to now when we've been living together and both been insanely busy with our respective studies. He is my favourite person, the best ent and I love him with all my heart.

Studying for a PhD has allowed me to meet some wonderful, charming and crazy people who have been students alongside me. There are more stories and people than I can name here, but some I couldn't not include. Caoimhe Doherty was a wonderful house- and flatmate for three years and introduced me to more pop culture from this millennium than a sheltered nerd like me had known before. Affelia Wibisono has helped me with so many outreach ideas, projects and applications whilst (barely) tolerating my puns. Ahlam Al Qasim and Aisha Al Mannaei who where my Arab parents and treating me to tea and snacks, even when they were annoyed at me for cutting my hair. Richard Haythorthwaite who was always ready for a crossword or for quoting Hot Fuzz or Monty Python. Fiona and Artemis McAllister, one of whom would make the most entertaining noises. Then everyone else I've shared an office with – including Anurag Deshpande, Nabil Brice, Hannah

Osborne, Auggie Marignier and Ioana Ciuca – who have made a day at work much more entertaining. I would honestly list more names, those of pretty much everyone who was a student at Mullard Space Science Lab for the four years I have been around, but this is getting a little too self-indulgent for my tastes.

Finally, to my Pathfinder group on RoleGate: SirKay, RabidSPG, Shakeitlove and Jiffypop. They have all been so much fun to play with and have been a great, nerdy, creative outlet for me when science was otherwise swallowing my brain. Does this mean I'm a Level 10 Expert now?

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Liew-Cain: Lead-author, carried out all the analsysis work, provided discussion and wrote the whole text. Kawata: Provided the initial idea and strategy of the work, and provided the support and discussion. Sanchez-Blazquez: Provided the stellar population analysis of the CALIFA data and construction of the J-PAS mock data. Ferrears, Symeonidis: Provided the support and discussion.

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Chapter 2

5. e-Signatures confirming that the information above is accurate (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work):

Candidate:	*Choong Ling Liew-Cain*	**Date:**	07/09/2022
Supervisor/ Senior Author (where appropriate):	████████	**Date:**	07/09/2022

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Chapter 1

Introduction

This chapter begins by discussing the origins of astronomy across the Earth in different cultures and at different times. In the past two centuries there has been more of an effort to share the findings of astronomers with the public. This is discussed briefly, using the discovery of galaxies beyond the Milky Way as an example. Galaxies are then discussed in more detail, in particular the properties of extragalactic stellar populations and the ways that astronomers observe them. Modern galactic surveys are producing data faster than some traditional methods of analysis are able to examine them. Neural networks are one way in which this issue is being addressed. Two common types of neural networks and how they are trained are then discussed, followed by examples of their application in recent stellar population studies. Reflecting on the earlier discussion of how public engagement with astronomy has developed over time, modern engagement of the public with astronomy is summarised. The effects of engaging with science are examined, including a discussion of science capital and how to make inclusion in science more equitable.

1.1 The relevance of astronomy to humanity

1.1.1 Historical relevance of astronomy

The study of the night sky has been of interest to humans for millennia. Across the globe, there have been civilisations who have observed the stars and planets, finding myth, meaning and science in what they saw.

1.1.1.1 Mesopotamia

Mesopotamia, the ancient civilisation which used to occupy what is now Iraq, Kuwait, Iran, Syria and Turkey, is considered to be the first place astronomy was developed.[1]. The Mesopotamians considered the stars to be messengers from their gods to their king. Therefore, many temples employed priests to keep records of the movements of the Sun, Moon, planets and stars. Over decades these data led to patterns being discovered, and so the Mesopotamians began to be able to predict the appearance and motion of the planets. Solstices and eclipses were also recorded and predicted by Mesopotamians, with tablets dating from around 1000 BC.

The geographic proximity of Mesopotamia to Greece led to the adoption of some Mesopotamian astronomy by later Greek astronomers. This included splitting the number of hours in a day, and days in a year, which were based on data collected by the Mesopotamians.

1.1.1.2 Ancient Greece

Like much of science, modern astronomy has developed out of the theories of ancient Greece. They are still included in astronomy education to this day, with the geocentric model of the solar system, developed in classical Greece, mentioned by name in the UK national curriculum for Key Stage 2[2]. The influence of classical Greek astronomy has been debated over the past two centuries, including whether it was Greek astronomy that influenced ancient India's astronomy or vice versa. Records of the development of astronomical techniques are shown in Greek texts, whereas astronomy appeared suddenly in a relatively mature form in Indian texts (Steele, 2016). This implies that it was Greek knowledge passed to the Indians, including planetary models (Steele, 2016) and transliterated technical language (Burgess, 1893).

In classical Greece, astronomy was studied by philosophers, with myth and spirituality attributed to the Sun, Moon and planets. Plato assumed that the planets

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[1]https://www.britannica.com/science/astronomy/
History-of-astronomy#ref314013
[2]https://www.gov.uk/government/publications/
national-curriculum-in-england-science-programmes-of-study/
national-curriculum-in-england-science-programmes-of-study

moved on circular or spiral tracks in the sky, which accounts for their motion. However, he stated "We shall let the heavenly bodies alone, if it is our design to become really acquainted with astronomy" (Hetherington, 1999) which is in contrast to the view taken by modern astronomers.

Ptolemy's Almagest (Toomer, 1984), written around 150 AD, was circulated among and used by astronomers in Europe and the Middle East until the 17th century (Encyclopedia Britannica, 2020). In Book 1, the fifth section is titled "That the Earth is in the middle of the heavens" (Toomer, 1984) and argues that based on his observations the universe is geocentric. In later sections, Ptolemy also describes trigonometric ways to deduce the motions of the planets, and begins a catalogue of the locations of stars in the sky.

The stars were important to general Greek citizens too, and not just saved for the philosophers or scientists. The use of the stars for navigation was known to the ancient Greeks, as demonstrated Homer's Odyssey:

> "[H]e watched the Pleiades and the late-setting Wagoner, and the Bear, or the Wagon, as some call it, which wheels round and round where it is, watching Orion, and alone of them all never takes a bathe in the Ocean.
>
> Calypso had warned him to keep the Bear on his left hand as he sailed over the sea." (Rouse, 1960, p89)

The constellations were designed by the Greeks to commemorate heroes and stories from their mythology. We still use these names for astronomical objects today, including the Andromeda galaxy and the Orion nebula.

1.1.1.3 Ancient China

The ancient Chinese made records of the stars, as well as transient objects which were referred to as "guest stars". These included novae, supernovae and variable stars (Zhao et al., 2006). There are also records of comets' appearances and motions across the sky.

Astronomy played a large role in the superstitions of the ancient Chinese peo-

ple. Rishu *(daybooks)* were widely distributed books containing auspicious and inauspicious days based on the position of the stars in the sky (Steele, 2016).

Other books relating astronomy to omens were found in ancient China. For example, the 168 BC manuscript referred to as Wu Xing Zhan (*Prognostics of the Five Planets,* Cullen, 2011) details the motion of Mercury, Venus, Mars, Jupiter and Saturn in the sky, and how they may impact political careers. The first large-scale history of China, Shi ji (*Records of the Grand Historian,* Sima, 1993) describes the presence of astronomy in ceremonies, for example "Emperor Shun, holding the jeweled astronomical instruments, checked the movements of the Seven Ruling Bodies", i.e. the Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn. Like the *daybooks*, these texts show that the position of the stars and planets had significant cultural importance in ancient China. These texts, unlike the *daybooks*, were only shared among the social elite and not distributed to the wider population.

1.1.2 History of astronomy outreach

Astrology and other superstitions relating to the stars have been seen throughout many levels of society. On the other hand, early books on astronomy were highly mathematical in content and needed significant levels of education to understand. This meant that understanding of astronomy was reserved for people who could afford to be educated, i.e. upper class men. After Galileo's use of the telescope, an additional cost was added to what was necessary to become an astronomer, as telescopes were soon needed to make new discoveries in the field. This again restricted astronomy to be a subject for the upper class.

The publication of books like Isaac Newton's Philosophiae Naturalis Principia Mathematica and Laplace's Exposition du système du monde *(The System of the World)*, helped to popularise astronomy (Meadows, 2000). These books explained astronomy and its history in ways which did not require a strong background in mathematics which made them accessible to the general public[3]. During the 19th century, astronomy journalism began in the UK, with magazines and newspapers

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[3]https://www.britannica.com/science/astronomy/Enlightenment#ref314031

publishing content for a lay audience.

At a similar period of history to the uptake in astronomy journalism in the UK, public lectures for astronomy began to take place and proved to be popular. To begin with, these lecturers didn't have any affiliations, but by the 1860s there was a shift towards lectures from universities or learned institutions. However, these people were not astronomy researchers (Huang, 2018), and the general sentiment was that researchers should be publishing in scientific journals rather than broadly accessible media.

In this period, it was not generally acceptable for women to be researcher or "professional astronomers". Therefore, many of them became science writers, including Agnes Clerke. She wrote articles and books explaining astronomy to people without a scientific background, including writing some sections of the *Encyclopedia Britannica*. She was criticised for not being an active observational researcher by other scientists, who believed that only people like them should be writing about astronomy. Despite this, Clerke was praised by both astronomers and the public for her writing, and was later offered employment at Royal Observatories in the Cape of Good Hope and Greenwich where she did get a chance to work with telescopes[4].

Whilst in the UK astronomy began to gather popularity with non astronomers in the 19th century, it was not until the 1950s that Astronomy was printed for a general audience in China. This was sparked by the government's desire to unite astronomers working on the history of astronomy in China (Zezong, 1981). Before that date, historical studies of Chinese astronomy were conducted by individuals, mostly focusing on the discoveries within their local area and interest.

In 1920, the Shapley-Curtis Debate, also known as the Great Debate, took place. The content of the debate was the presence of other galaxies in the universe, and the Sun's position within the Milky Way. Shapley believed that the Milky Way was the only galaxy in the universe, surrounded by smaller nebulae, and that the Sun was located away from the Galaxy's centre. Conversely, Curtis believed that these nebulae were separate galaxies, and that the Sun was located at the centre of

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[4]https://mathshistory.st-andrews.ac.uk/Biographies/Clerke/

the Milky Way. It was of great interest to contemporary astronomers, but not to the wider public; the media paid little to no attention to it (Trimble, 1995).

Hubble's later discovery, settling the debate and proving that there are galaxies other than the Milky Way, was also only given a small article in a newspaper when the findings were announced[5]. However, Hubble has now become a household name thanks to the outreach efforts associated with the Hubble Space Telescope. The telescope has its own dedicated outreach site[6] with news and images from the mission showcased and publicised. One of the most famous images is the Hubble Ultra Deep Field, shown in Fig. 1.1. A staggering number of galaxies can be seen in this small area of the sky. Images like these are not only inspiring to the public, but can be useful to astronomers as they try to learn more about galaxies.

1.2   Galaxies

Galaxies are the building blocks of the universe, so to understand the universe we need to understand galaxies. They formed early on in the universe's history, in regions of space where there were overdensities of dark matter. The high concentration of dark matter gravitationally attracted gas which was drawn into these overdensities and eventually collapsed into stars which were bound together by gravity into the form of a galaxy.

In modern times, galaxies are collections of dark matter, stars, stellar remnants, gas, dust and a supermassive black hole which are bound together by gravity. They can be found either alone as field galaxies or as part of a galaxy cluster, where they are gravitationally bound to other galaxies. Galaxies have two main morphology categories: early-types or late-types. Early-type galaxies, also known as elliptical galaxies, are usually larger, ellipsoidal, gas-poor and made up of old stars. Late-type galaxies, also known as disc or spiral galaxies, are typically more gas- and dust-rich, disc-shaped and actively forming stars. An example of a late-type galaxy can be seen in Fig 1.2.

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[5]`https://www.discovermagazine.com/the-sciences/`
`january-1-1925-the-day-we-discovered-the-universe`
[6]`https://hubblesite.org/`

Figure 1.1: The Hubble Ultra Deep Field. One of the most iconic and famous images from the Hubble Space Telescope. The majority of objects in this image are galaxies. Image from wikimedia, credits: NASA/HST.

1.2.1 Galaxy Evolution

Galaxies appear on the sky as large, stable structures, but are by no means static. The matter within them moves in gravitational orbits, and populations of stars are born, age and die within them. This means that the properties of galaxies changes over time, giving way to the field of galaxy evolution, in which astronomers decode the history of galaxies.

The contents and morphology of a galaxy have an impact of how it can evolve. Early-type galaxies are typically very gas-poor. As gas is needed to form new stars, early-type galaxies are unable to form new stars. On the other hand, late-type galaxies contain gas so can form new stars. Extragalactic gas can be accreted by galaxies due to their gravitational pull, but stellar activity can
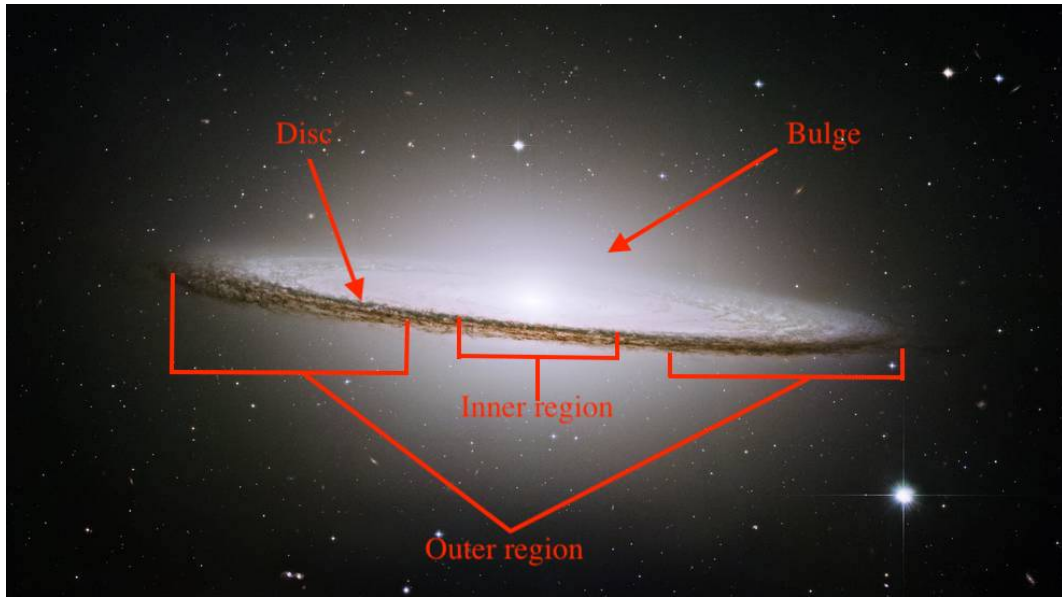
Figure 1.2: The late-type galaxy M104. The edge-on view of the galaxy allows us to see the bulge and disc components (labelled) easily. The inner region of this galaxy lies within a few kiloparsec (kpc) of galactic centre and the outer region is the parts of the galaxy at a higher radius. Figure adjusted from NASA/HST.

create a pressure that stops this extragalaxtic gas from being accreted and can even push interstellar gas out of the galaxy. These effects mean that galaxies can go through phases of star formation, creating populations of stars with varying ages, allowing astronomers to tell when in its history a galaxy was forming stars.

With the exception of small amounts of lithium, all metals (i.e. elements other than hydrogen and helium) were created in stars or by stellar remnants within galaxies. These metals can then be spread out through the galaxy though planetary nebulae or supernovae which happen at the end of a star's life. These metals then mix with interstellar gas and dust, which can then collapse and form new stars containing these metals. This means that by examining the metal content of stars (by looking at their absorption lines; common metallicity tracers used include iron, oxygen and nitrogen) astronomers can learn about previous generations of stars that lived and died in a galaxy which indicate its evolutionary pathway.

Due to their distance from the Earth, we are unable to resolve individual stars

in most galaxies. When we take observations of galaxies in visible wavelengths, we are observing light from a population of many stars within that galaxy. The properties of the galaxy we deduce are therefore the average of the properties of the stars at that location within the galaxy.

As the timescale for galaxy evolution is often billions of years, if not more, astronomers consider observations of a single galaxy to be a snapshot in time of its evolution. Observations of multiple galaxies of the same type at different redshifts are used as a series of captured images from different points in a typical galaxy's life.

Two parameters of interest to astronomers are the age and metallicity of stars. Stellar age tells astronomers how long ago a star was formed, and stellar metallicity, i.e. the abundance of elements heavier than helium within the star, can tell astronomers about previous generations of stars. Galactic age and metallicity, and their distributions within galaxies, provide detailed information about the evolution history of their stellar populations. The value of galactic age and metallicity is the average of the respective stellar parameter across a population within the observed galaxy. Traditionally, age and metallicity have been measured by fitting spectral data to stellar populations (e.g. Worthey, 1994; Bruzual, Charlot, 2003; Trager et al., 2000; Conroy, 2013; Sánchez, 2020). Models such as these have identified spectral lines **whose strength correlates with the age and or metallicity of stellar populations the light originates from (e.g. Sarzi et al., 2006; Worthey, 1994). The strength of the lines indicates the abundance of the corresponding element. Due to the relatively low number of degrees of freedom in stellar spectra, not all of the information from the stellar absorption lines is lost in SEDs even though we cannot see the spectral lines. For example, Beck et al. (2016) used principle component analysis and linear regression to reconstruct absorption lines from SDSS spectra from information contained soley within the spectral continuum.** Traditional spectral and photometric analysis methods are able to break the age-metallicity degeneracy (Worthey, 1994) and have enabled reliable values for age and metallicity to be derived by modern instruments.

If a galaxy is observed with a single spectrum or SED, its light would be dominated by its central region. This is because, for both late- and early-type galaxies, the density of stars is typically greatest near the galactic centre. As well as stellar density, there can be other characteristic differences which vary with radius in a galaxy, such as the abundance of gas and dust, angular momentum or feedback mechanisms. This means that the evolution of stellar populations within the same galaxy can be different depending on their distance from galactic centre. Therefore, to understand the evolution of the whole galaxy, it is useful to examine multiple spectra or SEDs taken from different regions across the projected surface of a galaxy. These observations can be combined to give radial profiles of stellar population parameters which can allow us to see if galaxy centres formed before their outskirts or if the whole structure evolved together.

Observing galaxies at different redshifts can provide further information about how galaxies are built up, as looking at higher redshift galaxies is equivalent to looking further back in time. Redshift is defined as

$$z = \frac{v}{c} = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}}$$

where v is the recession speed of the galaxy, c is the speed of light, λ_{rest} is the wavelength of an emission line in the rest frame and λ_{obs} is the wavelength of the same emission line observed. The evolution of Milky Way-like galaxies with redshift $z \lesssim 2.5$ has been discussed in van Dokkum et al. (2013). The authors identified progenitors of the Milky Way by assuming that the comoving density of Milky Way-like galaxies is constant throughout time. The authors derived the dependence of galactic stellar mass and star formation rate on redshift and found evidence that Milky Way-like galaxies are not formed "inside out", i.e. forming their inner regions at earlier times than their outer regions, as was believed previously. Instead, the galaxies' bulges and discs were formed simultaneously at $z > 1$. After this time, star formation in galactic bulges is suppressed while formation in the disc continues at a gradually decreasing rate. This work is supported by the findings of Hasheminia

et al. (2022). Using near-infrared Integral Field Unit (IFU) data from the K-band Multi-Object Spectrograph (KMOS) 3D survey, Wuyts et al. (2016) found that only 15 in the sample of 180 star-forming galaxies at $0.6 < z < 2.7$ had flat metallicity gradients and there was no dependence on redshift. This also indicates that the majority of galaxies in the authors' sample formed inner and outer regions together.

The evolutionary histories for elliptical or early-type galaxies are widely studied with stellar population models. Using the medium-band instrument Advanced Large Homogeneous Area Medium Band Redshift Astronomical (ALHAMBRA) Survey, metallicity and age gradients were determined for 29 nearby elliptical galaxies (San Roman et al., 2018). The authors found that the age gradients of this sample were flat (i.e. stellar ages consistent across the galaxy) and metallicity gradients were slightly negative (i.e. higher metallicity at the centre of a galaxy than its edges). Ferreras et al. (2019) found that in elliptical galaxies, their age gradients correlated with surface mass density and metallicity gradients were correlated with their velocity dispersion. However, the strength of this metallicity - velocity dispersion correlation varied depending on the metallicity tracer chosen. There was little dependence on whether the galaxy was located in a cluster or group of galaxies or alone in a field.

1.2.2 Observational studies of stellar populations

When we observe galaxies there are traditionally two methods which are used. Spectroscopic observations typically observe small or single regions of space, but can have very fine spectral resolution so **emission lines from interstellar gas and absorption lines from stellar atmospheres** can easily be seen. **This allows** for the deduction of galactic stellar population properties. Photometric surveys, on the other hand, can cover wider regions of the sky and have a fine spatial resolution across the full field of view for the detector. However, they integrate over many wavelengths so do not provide the same level of information about galaxies' stellar populations as spectroscopic observations.

1.2.2.1   Spectroscopic studies of galactic stellar population

The determination of the stellar population properties in galaxies is one of the most powerful techniques to understand the formation and evolution of galaxies. Traditionally, this has been done by comparing the absorption line spectral features with stellar population synthesis models (e.g. Worthey, 1994; Bruzual, Charlot, 2003; Vazdekis et al., 2010; Conroy, 2013), using spectral indices (e.g. Trager et al., 2000; Sánchez-Blázquez, 2016) or, more recently, using full spectral fitting techniques (Panter et al., 2003).

Over the past few years, galactic spectra have been obtained by Integral Field Unit (IFU) surveys, including Calar Alto Legacy Integral Field Area (CALIFA, Sánchez et al., 2012), Mapping Nearby Galaxies at Apache Point Observatory (MaNGA, Bundy et al., 2015), Sydney-Australian-Astronomical-Observatory Multi-object Integral-Field spectrograph (SAMI, Croom et al., 2012), *K*-band Multi Object Spectrograph (KMOS, Wisnioski et al., 2015). IFU instruments take spectroscopic observations of galaxies over their projected surface in the sky, resulting in many spaxels (i.e. the spectrum within each pixel). An example of an IFU observation is depicted in Fig. 1.3. Each spaxel covers part of the galaxy, much like an image's pixel would in photometric observations, and the observation contains a spectrum resulting from the stellar populations within that area of the galaxy. These IFU surveys can be used to produce two-dimensional distributions of age and metallicity to be studied for different galaxy types. These spatially resolved spectra have put strong constraints on galaxy formation and stellar population synthesis models (e.g. Belfiore et al., 2019; Sánchez, 2020).

The CALIFA IFU survey (Sánchez et al., 2012), which will be discussed further in Section 2.2.1, used the PMAS/ PPAK integral field spectrograph, mounted on the Calar Alto 3.5 m telescope. Each galaxy in the dataset was observed three times, with dithering used to reach a spectral resolution of ~ 1". The IFU allows 2D spectra in a grid over the surface of the galaxy to be collected, through exposure times of 1800 s and 900 s for the blue and red gratings respectively. The CALIFA parent sample consists of 937 galaxies selected from the Sloan Digital Sky
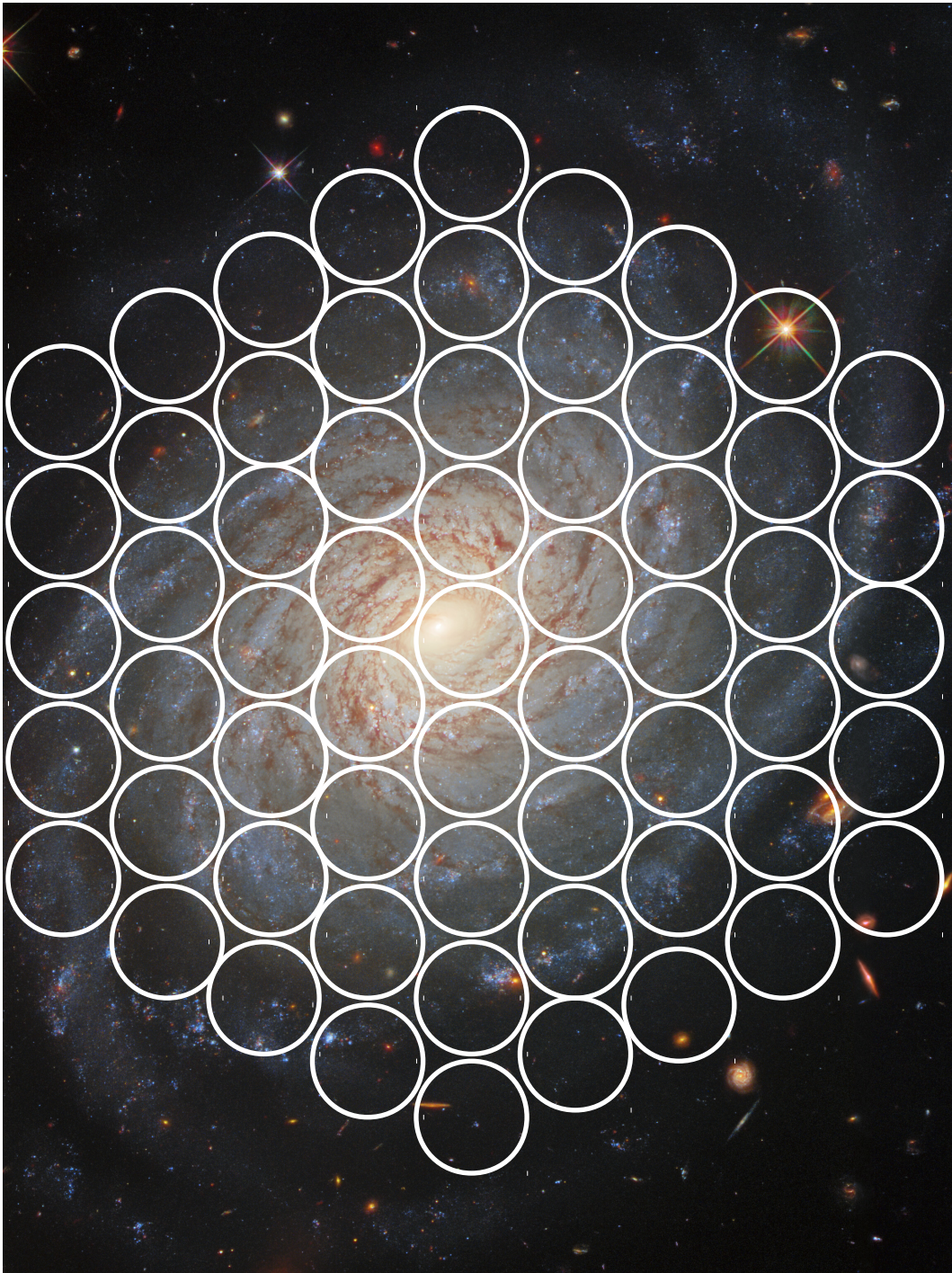
Figure 1.3: A schematic depiction of an IFU observation of a galaxy. The white circles represent spaxels, which are small regions from which instruments extract spectra. Using these spectra, the properties of stellar populations in that galaxy can be determined. Figure adjusted from NGC976, wikimedia commons `https://commons.wikimedia.org/wiki/Category:NGC_976#/media/File:NGC976_-_HST_-_Potw2202a.jpg`.

Survey's (SDSS) 7th data release within $0.005 < z < 0.03$, with the majority being field galaxies. From the parent sample, ~ 600 galaxies were observed with a diameter limit to fit within the IFU field of view and down to $M_B \sim -18.0$ mag

1.2.2.2 Narrow-band photometric studies of galactic stellar populations

An alternative to spectroscopic surveys comes from narrow band filter imaging. Photometric surveys are more efficient at observing fainter objects than spectroscopic instruments, and can cover a greater area on the sky in a single observation. Photometric observations with a single filter do not provide detailed properties of galactic stellar populations. However, photometric observations with many filters covering a range of wavelengths mean that the flux distribution at different wavelengths can be obtained and which aids in the study of galactic stellar populations (Conroy, 2013). Whilst narrow-band photometric studies do not have as high quality spectral resolution as modern spectroscopic instruments, photometric observations are more efficient as galaxies are not pre-selected, unlike in spectroscopic surveys. Instead, all galaxies that are brighter than the limiting magnitude in the field of view will be observed. Narrow and medium band filter surveys, such as Classifying Objects by Medium-Band Observations (COMBO-17, Wolf et al., 2001), Survey for High-z Absorption Red and Dead Sources (SHARDS, Pérez-González et al., 2013), Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS, Benitez et al., 2014), Javalambre Photometric Local Universe Survey (J-PLUS, Cenarro et al., 2019) and Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al., 2019), effectively act as low spectral resolution IFU surveys, producing spectral energy distributions (SEDs) at many positions within the galaxy. These SEDs contain enough information to derive an average stellar age and metallicity (e.g. San Roman et al., 2018). A photometric observation with four bands is depicted in Fig. 1.4. Narrow or medium band instruments typically have many more bands than this; for example, J-PAS has 30 bands giving a higher spectral resolution.
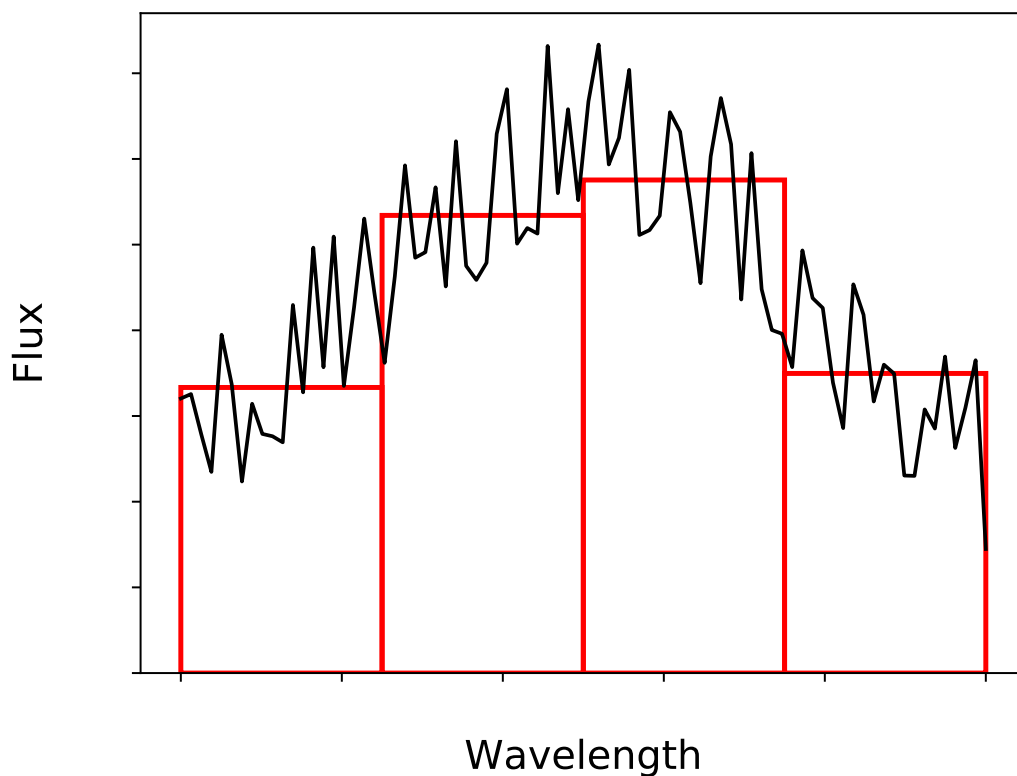
Figure 1.4: The schematic shape of four filter bands (red rectangles) to a schematic galaxy spectrum (black line). The width of the red rectangles indicates the wavelength range over which the filter detects transmitted flux. The height of the rectangles schematically describes the flux of spectra within each filter band.

Díaz-García et al. (2015) used ALHAMBRA data to derive redshift, metallicity and age and compare these values with spectroscopic observations of the same galaxies. The Multi-Filter Fitting for stellar population diagnostics (MUF-FIT, Díaz-García et al., 2015) code they developed shows good recovery of the spectroscopic values, though results are highly dependent on the choice of stellar population model. San Roman et al. (2019) analyses two elliptical galaxies, NGC 5473 and NGC 5485, observed by four broadband, two medium-band and six narrow-band filters on J-PLUS. The radial gradients for age, metallicity and extinction that are derived are in reasonable agreement with CALIFA survey observations of the same galaxies.

1.3 Machine Learning in Astronomy

A challenge emerging from narrow-band surveys is the volume of data to be analysed. For example, J-PAS aims to observe a total of 9×10^7 galaxies with multiple pixels per galaxy. Additionally, J-PAS and J-PLUS together are expected to collect a maximum of 1.5 TB of data per night (Benitez et al., 2014). Therefore, a computationally efficient method for deriving stellar population parameters from the data is required, and will become invaluable in the future with larger surveys.

Traditional spectral (e.g. Ocvirk, 2011; Sarzi et al., 2006) and broad- or narrow-band SED (e.g. Díaz-García et al., 2015) analysis tools have been used to derive stellar population parameters. This is typically done by fitting models to account for the strength of absorption lines and continuum flux of an observation. However, these traditional methods of analysis are time consuming and do not scale well with large datasets. On the other hand, neural networks are a tool that shows promise in overcoming this challenge (e.g. Folkes et al., 1996). **Once trained, neural networks are able to quickly analyse large volumes of data. As well as traditional computer processing units, neural networks are able to use graphics processing units (GPUs) which can lead to faster training and application times for neural networks. Additionally, the software libraries for neural networks are open source and widely available (e.g. Abadi et al., 2015), making them an accessible choice of tool to efficiently analyse large volumes of data.**

1.3.1 Neural networks

Neural networks are algorithms that allow non-linear mapping between input and target parameters, and are efficient methods of analysing large datasets. Their design is inspired by how human brains work. A neural network is made by connecting a series of nodes together, mimicking neurons in the brain. The network then takes some data, processes it by making non-linear combinations from previous connected nodes, then making a prediction. Typically, neural network predictions are either to categorise objects (e.g. categorising galaxies by morphology) or to solve a regression problem (e.g. determining a galaxy's age).
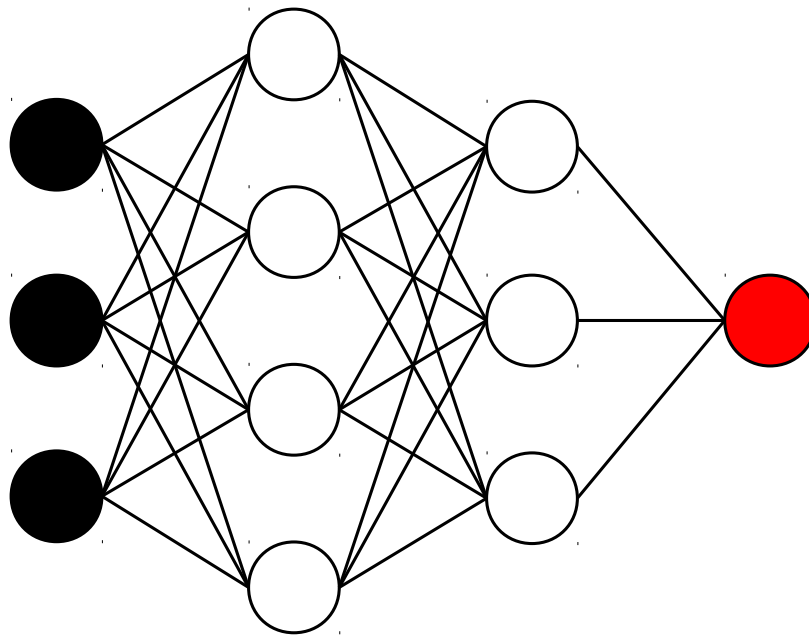
Figure 1.5: A schematic for a neural network with two hidden layers. The input data are shown in black on the left of the figure and the output label is shown in red on the right. White circles represent nodes in the hidden layers. The first hidden layer has four nodes and the second has three. The lines connecting the circles show the connections between nodes which are each given a weight. As the neural network trains these weights are altered in order to make more accurate predictions.

Fig. 1.5 shows a schematic of a neural network designed to solve a regression problem. Each column of nodes (circles) is called a layer. The black circles on the left represent the input data, for example the luminosity of a region of a galaxy as observed by an instrument's filters. The red circle on the right represents the output label, such as the average age of stars within that portion of the galaxy. The white circles are the hidden nodes of the neural network. The number of hidden (white) layers and nodes within each layer (referred to as an architecture) can be changed in order to suit the problem which the neural network is being used to solve. In general, increasing the number of nodes or layers in a neural network's architecture can produce better predictions. However, it also increases the time taken for the neural network to train and increases the chance of overfitting (which
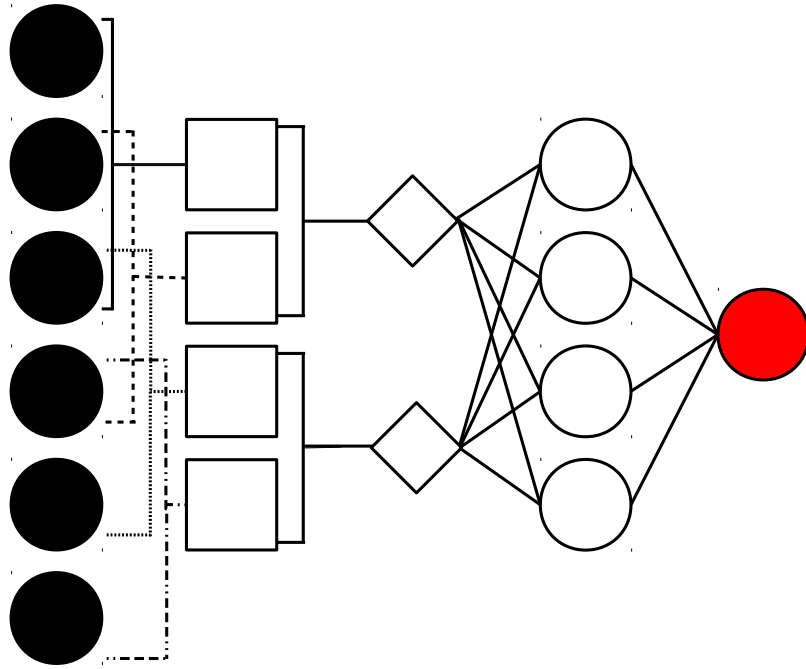
Figure 1.6: A schematic for a convolutional neural network. The input data is on the left and coloured in black and the output label is on the right of the figure and coloured red. The squares show the convolutional layer, and the rotated squares represent the pooling layers. The white circles represent nodes that act in the same way as the nodes in the neural network described in Fig. 1.5.

will be discussed later).

Each node combines the previous node values in the following way:

$$y = a_1 x_1 + a_2 x_2 + ... + a_n x_n + b \tag{1.1}$$

where y is the value of the node, $x_{1,...n}$ are the values of nodes in the previous layer (composed of n nodes), $a_{1,...n}$ are the weights associated with each node in the previous layer and b is a bias value. These values change during as the neural network is trained.

1.3.2 Convolutional neural networks

Convolutional neural networks (CNNs) are particularly good at looking for features within images. CNNs are a subset of neural networks that use convolutional layers

to look for patterns across multiple input data points. The architecture of an example CNN is shown in Fig. 1.6. As in Fig. 1.5, the input data and output label are represented as black and red circles, respectively. In this example, we consider the input data to be 1-dimensional (such as spectra), though CNNs are more commonly applied to 2-dimensional data (like images of galaxies). The squares in the first hidden layer represent convolutional filters. In this example, the convolutional layer has a filter size of three, i.e. it examines three nodes simultaneously and computes the weighted sum of the three input values. This is repeated for each group of three consecutive nodes in the previous layer. The filter weights used in summing change during CNN training, and filter size can be adjusted to improve predictions. In Fig. 1.6 only one convolutional layer and filter later are shown for the clarity of the figure, but multiple convolutional layers are usually included in an architecture.

After the convolutional layer (or group of layers) a pooling layer is used, represented in Fig 1.6 by the rotated squares. Pooling layers make the results of CNNs more stable; convolutional layers are prone to having very variable values when looking at fine details. Therefore, the pooling layers group the outputs of the convolutional filters and consider either the average or maximum of these values and feed this number forwards. Pooling layers also reduce the number of data to be used in later hidden layers of the neural network.

The layers used in neural networks architectures described in Section 1.3.1 can also be used in CNNs, as shown by the white circles in Fig 1.5. The way they function is explained above in section 1.3.1. The training of CNNs is also identical to that of neural networks described above, and their application is also very fast and efficient once they are trained. Therefore, CNNs are also used widely in astronomy research.

1.3.3 Training a Neural Network

A supervised neural network is given a training set, a verification set and a testing set when it is used. The training and verification sets both contain input data and output label(s). The training set chosen needs to be representative of the data the neural network will be making predictions from. If the training set and this final

application set are too dissimilar, then the neural network's output labels will not be accurate. Therefore, selecting an appropriate training set is a vital step in neural network methods. For example, galaxies have a diverse formation history and therefore the training set needs to cover this wide variety of galaxy evolution. Otherwise, the neural network will not be capable of accounting for the diversity present in galaxy surveys.

The neural network starts with random weights between each node and a random bias (a_n and b, respectively, in equation 1.1). During the process of training, the neural network computes a prediction or an output label using the training data. This is compared with the output label initially given to the neural network, which is taken to be the "true" value. The error in the prediction is then back propagated through the neural network, with the weights and biases being adjusted to bring the predicted value close to the true value. These training steps are repeated a set number of times (known as epochs) or until the error between true and predicted values reaches a certain threshold which can be specified.

Another problem with using an architecture with many nodes or many layers is the problem of overfitting. This is where the neural network begins to fit to the small details particular to the training set, and not representative of the whole dataset. This can be seen when using a validation set. Since the neural network is not trained on the validation set, when overfitting starts to occur then the error between predicted and true values for the validation dataset will begin to increase. This can be seen in the schematic loss curve shown in Fig. 1.7. To the right of the dashed vertical line, the error for the validation set begins increasing while the error for the testing set is still decreasing.

There are multiple ways of avoiding overfitting. The training of the neural network can be set to end once the error of the validation set stops decreasing. Another method is known as dropout, where each layer can be given a probability for the weight of each node to be set to zero (i.e. $a_n = 0$) for one epoch. As mentioned previously, the architecture can be changed to decrease the number of nodes or layers.
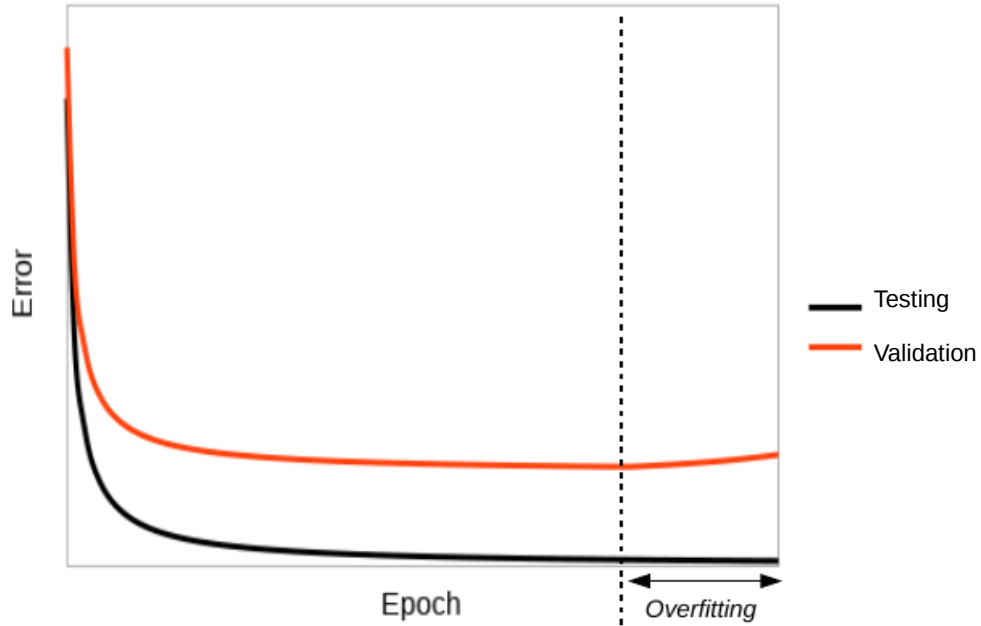
Figure 1.7: An example loss curve, showing how that the error changes over subsequent epochs for both the testing and validation sets as the neural network trains. Overfitting can be seen to the right of the vertical dashed line, as the error of the validation set begins to increase while the error of the training set continues to decrease.

When the training the neural network has been completed, the model is then applied to a testing set. The testing set is composed of input data and corresponding "true" output values, which have not been used in the training or validation steps. The trained neural network makes predictions from this input data, which are then compared to the "true" values for the testing set.

1.3.4 Application of machine learning to galactic stellar population studies

Once the model has been trained and deemed to produce adequate predictions, it can then be used to make predictions. For this, it is given the application data set, which is composed solely of input data. Producing predictions using a trained model is quick and computationally cheap, so is very useful for situations where we

are dealing with big data, including astronomical images.

Machine learning is applied widely in astrophysical research (e.g. Folkes et al., 1996; Baron, 2019) and has been used to derive the metallicity of galactic stellar populations from broad band photometric surveys previously. Acquaviva (2016) and Wu, Boada (2019) applied random forest algorithms and neural networks, respectively, to calculate the metallicity of galaxies from multi-wavelength SDSS photometric observations, with SDSS spectral age and metallicities used as training data. One of their findings was that increasing the number of photometric filter bands used to train the neural network improved the accuracy of the predicted metallicity value of the galaxy. MIRKWOOD (Gilda et al., 2021) is a machine learning based code which was trained on synthetic SEDs generated from galaxies **in** cosmological simulations. It can be used to make predictions of stellar population properties from real SEDs with a greater confidence and precision than SED fitting methods. The neural network method employed by Simet et al. (2019) was trained on semianalytic galaxies and gives results with an error comparable to that of traditional SED fitting methods for galaxies in the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDLES) dataset for stellar mass and star formation rate predictions. The authors also find that the redshift of the galaxies in their sample did not have an impact on the accuracy or precision of the predicted stellar population parameters, implying that the neural network model does not need explicit redshift information to make useful predictions. **CANDLES observes galaxies with redshifts** $1.5 < z < 8$**.**

Lovell et al. (2019) used the results of cosmological simulations of galaxies to synthesise SDSS-like spectra. The authors included simulated effects of extinction and noise when creating these spectra. CNNs were trained on these SDSS-like spectra to determine galactic star formation rate over cosmic time. Surana et al. (2020) used a neural network with three hidden layers to determine the star formation rate and star formation history of 76,455 galaxies observed by the Galaxy And Mass Assembly (GAMA) survey with reasonable accuracy compared to traditional stellar population synthesis models.

1.4 Engaging non-scientists with science

1.4.1 Public engagement

After making discoveries about our universe or developing new techniques, astronomers may communicate their findings **to** non-scientists. The desire to communicate could be from enjoyment, requirements of a funding agency, desire to consult with stakeholders in their research outcomes or because they believe their research or its impact is important for others to know about. There are many potential publics with which they can share their knowledge and/or engage in astronomy. Similarly to the late 19th- and early 20th century, cutting-edge astronomy research is included in media reporting cycles at the current time. However, in those times dissemination was left to outreach or engagement professionals whereas now these events typically feature the scientists and engineers directly involved in the findings.

1.4.1.1 Events targeting adults

For the majority of adults who have left education, engagement with astronomy is usually encouraged through entertainment events. This could include visits to museums, science centres, festivals and other informal learning centres as a family event (Pompea, Russo, 2020). Some of these venues have introduced "Lates" or similar events, which are targeted at adults only. Other adult only events include Pint of Science[7] and Bright Club[8]. However, many of these forms of engagement primarily offer one-off events to entertain and offer knowledge of astronomy to people who are already motivated and able to attend. These events usually focus on one-way engagement, i.e. disseminating knowledge to the public, and focus on increasing knowledge of science or inspiring their audiences. Research has shown that a lay audience is more likely to take part in scientific research if the subject covered is related to the person's goals, interests and everyday life (Dreyer et al., 2021). For example, several everyday technologies have been developed for improving astronomical observations or as a result of astronomers' findings. This includes the development of CCDs now used in cameras, x-ray scanners used in transport or

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[7] https://pintofscience.co.uk/
[8] https://brightclub.wordpress.com/

security and the development of wifi (Fabian, 2010). Furthermore, astronomy has been shown to be more accessible than other areas of science to an audience that do not consider themselves as scientists (Smith, 2003).

1.4.1.2 Citizen Science

Citizen science is a movement which encourages non-scientists to take part in scientific research, typically by processing large datasets. There are many astronomy-based citizen science programmes running, including Galaxy Zoo (Lintott et al., 2008), Planet Hunters (Fischer et al., 2012) and Space Warps (Küng et al., 2015).

Citizen science is a consultancy-based form of public engagement (Reed et al., 2018); non-scientist participants are able to meaningly contribute to programmes through activities such as collecting or processing data, but have less agency into how it is used or written into papers. Many people regularly take part in citizen science, including those who do not work as scientists (Martin, 2017) . Phillips et al. (2019) found that participants in six environmental citizen science projects, 58 of 72 interviewees took part in the programmes because they wanted to contribute to science and that 52 of them were interested in the topic. During the interviews, 614 mentions to positive experience were made by participants, compared to 425 negative experiences, which shows that citizen science is enjoyable to those who choose to take part.

The demographics of people who take part in citizen science are not representative of the populations of those areas. Adult participants are very likely to hold post-16 qualifications in science, with many holding graduate or post-graduate science degrees (Martin, 2017; Allf et al., 2022). 88-96% of people who took part in multiple citizen science programmes were White, compared to 60% of the US population at the time the data were collected (Allf et al., 2022). This shows that, similar to one-way public engagement, the diversity of people who take part in citizen science is not representative of their population.

1.4.1.3 Schemes for children and students

Many programmes using astronomy for educational purposes are targeted at school and university-aged students. These also tend to focus students' gain of astronomical or astrophysical knowledge. For example, Ruggiero et al. (2021) have worked with 10-11 year old children to teach Einsteinian gravity in classrooms. Studies have also shown that working with older children and university students has been effective in increasing their enjoyment and understanding of astronomy, particularly when they can work with real data or telescopes (e.g. Dwarkadas, 2022; Trotter et al., 2019; Kautsch et al., 2021; Barton, Tan, 2010). In particular, Rafelski et al. (2010) found that using problem-based learning with real data in high schools and colleges in the USA led to greater knowledge gain of astronomy and techniques used by astronomers, and the developing of scientific thought processes among students. Other works have shown that inquiry-based projects have been effective in increasing levels of interest in science and understanding of concepts (Pompea, Russo, 2020).

Research has shown that prolonged experience working with scientists or multiple interactions with the same programme has a greater beneficial effect than one-off events. Archer et al. (2021) found that one-off visits or experiences had little to no lasting effect on school students' aspirations to become scientists, and that instead interventions over time should be incorporated more into school activities where possible. The ineffectiveness of one-off visits was also one of the findings of the ASPIRES 2 survey (Archer et al., 2020), a longitudinal survey of the attitudes towards science and the science capital **(see Section 1.4.2)** of a group of UK school students over 10 years. This study found that to support pupils' science capital it was more beneficial for scientists to work in partnership with schools, and to focus on making sure that science is taught using equitable teaching methods instead of changing considering course content.

Trotter et al. (2019) discussed the ways in which college-level introductory astronomy courses can be adapted to increase the interest of students taking the courses. The authors report that many people who took this course did not study

other science courses, which demonstrates the that astronomy can be used to reach an audience who are generally not interested in science. One of the key findings of that work was that the only factor that showed a correlation with positive attitudes to astronomy is the use of the Skynet robotic telescope network during the course. The other factors, including course content and quality of teaching, did not show any correlation with student attitudes to astronomy. From this, we believe that using actual astronomical data can be inspiring to the participants and have a positive impact on their views on astronomy, which is one of our goals. The success of astronomical data in teaching exercises is also seen in other works (e.g. Rafelski et al., 2010; Dwarkadas, 2022).

1.4.2 Science capital

Archer et al. (2015) developed science capital as a tool to quantify and understand patterns in the science-related aspirations of young people. **Science capital is defined as the sum of a person's science-related knowledge, attitudes, experience and resources. This includes factors such as science literacy, attitudes and values, consumption of media, participation in optional scientific activities, knowing scientists and talking about science.** The tool is an extension of Bordieu's work on capital (Bordieu, 1986), which has been used in the context of the arts, to make it applicable to science. This new form of capital is formed from the set of other forms of capital which relate to science and help people to gain value from scientific experiences. These include specific forms of cultural (e.g. attitude towards science and science-related jobs) and social (e.g. knowing a scientist or having a supportive family) capital, behaviours (e.g. engagement in optional science activities) and feelings about how someone identifies with science. Archer et al. (2015) compute a science capital "score" which aims to determine their engagement with science, strongly correlating to the likelihood of a student wanting a career in science and to study post-16 science. **People** with a lower science capital "score" are generally likely to feel less engaged or confident around science and do not feel that science is a (valuable) part of their lives[9]. The authors suggest that an effective way

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[9]https://council.science/current/news/science-as-a-global-public-good

to support the students who were deemed to have "low" science capital score is to work to change students' and families' attitudes to science.

Science capital was found to be a more effective indicator than either cultural capital or demographics of how likely school children are to continue to study post-compulsory science (DeWitt et al., 2016). More recently, it has been used to assess how engaged an adult audience is with science. **One of the aims of the national Public Attitudes to Science survey (DfBEIS, 2020) is to estimate the science capital of UK citizens. The survey's findings on science capital were taken from a literature review and face-to-face interviews with 1749 people ages 16 and older. The survey found that in the preceding 5 years there is more trust in scientists and belief in the importance of science among the population. DfBEIS (2020) also found that, while 82% of people think that science is a large part of their lives and people should be interested in the subject, fewer people (65%) think that it is important for them personally to know about the science in their lives.**

The Public Attitudes to Science survey (DfBEIS, 2020) found that, across the UK population, 18% of people had low science capital, 50% had medium science capital and 22% had high science capital. The authors also found that degree-educated people were much more likely to have high science capital (42%) than people without a degree (1%); men were more likely to have high science capital than women (29% and 14%, respectively; other genders were not mentioned) and people from "BAME backgrounds" generally had slightly higher science capital than "white people" (29% and 21%, respectively). Archer et al. (2015) find similar results among children in English schools. Boys were more likely to have higher science capital than girls (other genders were not mentioned) with boys comprising 54% of the high science capital group compared to 46% of the total sample. The authors also found that South Asian students were overrepresented in the high science capital group (14% of the high science capital group compared to 8% of the total sample) and White students were underrepresented in the high science capital

group (63% of the high science capital group compared to 74% of the sample). East Asian/Chinese, Black and Middle Eastern students also had higher average science capital scores than White students.

1.4.3 Inclusion in science

Previous literature has also shown that students can be put off science during their time at **school** (Archer et al., 2020; Dawson, 2019). Archer et al. (2015) found that of their sample of 3,658 students of aged 11 - 15 in the England, those with "high" science capital were more likely to be male and have higher levels of cultural capital (used as an analogue for social class). It is important to address inclusivity issues, which become even more pronounced for underrepresented groups, including gender and ethnicity. Maries et al. (2022) observed that in some physical science courses in one USA university that women who dropped their major in their 4th years had an average GPA difference of only 0.2 points compared to the average GPA of men who graduated and therefore there must be other reasons that cause women to drop out that are not related to their grades. DeWitt, Bultitude (2020) find that across European school children, respect is shown for careers in the space sciences, but girls in the study do not see themselves as having access to the profession. However, the gender diversity is **better in space science** than in the rest of the physical sciences[10] which offers hope that astronomy can **be used to inspire people to spend more time in scientific environments or doing more scientific activities.**

Dawson (2019) discusses some of the barriers that prevent people from accessing science learning environments. She notes that the way that outreach practitioners, including those working in science museums, attempt to engage new audiences is often based **on** a belief that the audiences are ignorant or possess some negative quality which keeps them away from science. An example of this supposed "defect" or negative quality could be lack of education or ignorance on the part of the people who do not engage with science. The idea from there, whether conscious or

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[10]e.g. DeWitt, Bultitude (2020), `https://www.iop.org/sites/default/files/2020-07/Student-characteristics-2017-18.pdf`

subconscious, is that if this deficit is "fixed" then the audience will enjoy science. This is based on the belief that science, when correctly understood, is universally appealing and so if a person can be made to understand science they will enjoy it and engage with the subject in the future. The author found that science qualifications from other countries, and particularly developing nations, were not recognised by the science sector in the UK. People with qualifications from developing countries are perceived to have defects that prevent them from adequately understanding science. Consequently these people, who were interested in science, were driven out of the science job market, and stopped engaging with science at all after this.

The deficit model of public engagement has been in place for decades, but recent studies have advocated for alternative models (e.g. Reincke et al., 2020; Seethaler et al., 2019) **which focus on creating dialogues between scientists and their audiences, including drawing on the lived experiences of the audience.** Historically, supposed deficits have also been linked to ethnicity, gender and class which led to exclusion from science based on those characteristics. The deficit model is still widely used in engagement today (e.g Dawson, 2019; Simis et al., 2016) which creates barriers preventing people, particularly those from underrepresented groups, from engaging in science. Simis et al. (2016) attributes the continued use of the deficit model of public engagement is due to the lack of formal training or knowledge of the literature about of public engagement, and viewing non-specialists as others who don't hold meaningful views about science.

As stated in Dawson (2019, p34), "the more prestigious, or dominant, a given field is, the more inaccessible it is (Johnson, Bourdieu, 1993)". Given the history of astronomy as being a subject only of concern to the societal elite, this can lead to astronomy being seen as inaccessible to people who are not already involved in science. However, other findings of Dawson (2019) show that whilst science, or areas of science "as abstract concepts" can seem intimidating and inaccessible, specific areas can be made to feel more welcoming. This finding can be of use to public engagement practitioners, as making an area more grounded, specific and relevant can make it more accessible. The findings of Archer et al. (2020), where

the impact of engagement is greater if the topic can be related to the audiences' lives, complements the focus on specific areas of science.

1.4.4 Why inclusion is important

The previous two sections have discussed how people are being excluded and potential ways of including them in the future. This section discusses the benefits that come with increased inclusion in astronomy.

Engagement with science has benefits for the audiences. Careers in the science sector and those that use skills developed in studying science, such as numeracy and critical thinking, pay above average salaries. In 2019, the average salary for someone working in science was £40,000[11], which is about £10,000 per year higher than the 2019 national average salary[12]. This has important consequences for social mobility.

A scientifically literate population is beneficial for a country. They will be more likely to participate in making laws of scientific issues (DfBEIS, 2020) and follow the laws if they understand the science behind them. This includes getting vaccinated (which is particularly relevant given this thesis was written during the Covid-19 pandemic) which would lead to a healthier country with fewer instances of preventable diseases, freeing up time and money to be spent elsewhere.

A diverse population of scientists is good for the progress of science. Scientists from different backgrounds and with differing lived experiences bring varied knowledge and skill sets, all of which benefits science. It has been found that diverse teams of scientists tend to have more paper publications and citations than non-diverse teams, and the former are better able to engage communities in their research[13]. Engagement with communities can lead to support of scientific research as well. Since a large proportion of the funding for university research, including astronomy, comes from the UK government[14], having the backing of taxpayers is

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[11]https://jobs.newscientist.com/en-gb/article/uk-science-salaries-top-40k-for-the-first-time/

[12]https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/bulletins/annualsurveyofhoursandearnings/2019

[13]https://www.nature.com/articles/d41586-018-05316-5

[14]https://publications.parliament.uk/pa/ld201719/ldselect/

important. Inclusion in astronomy can also mean access to funding from multiple nations or agencies. For example, the European Space Agency has funding available exclusively for people and organisations within one of their member states[15].

1.5 Scope of this work

Chapter 2 details a proof-of-concept study where we use convolutional neural networks to determine the age and metallicity of galaxies from narrow-band photometry. The data we used were synthetic SEDs which were synthesised from IFU data convolved with the response filters from J-PAS data (Benitez et al., 2014). We demonstrate that our CNN model can consistently recover age and metallicity from each J-PAS-like spectral energy distribution. The radial gradients of the age and metallicity for galaxies are also recovered accurately, irrespective of their morphology. However, it is demonstrated that the diversity of the dataset used to train the neural networks has a dramatic effect on the recovery of galactic stellar population parameters.

Chapter 3 covers work with people seeking employment in the cultural sector to develop an astronomy themed public engagement programme for this novel audience. We cover our work developing a course which aims to develop skills, chosen by the audience, which could help them to find a career. We have used survey and co-creation methods to develop this course, as contributions of our audience's lived experience allows the course we develop together to be more useful, equitable and accessible. The development of a pilot workshop using our findings is presented in Chapter 4.

Conclusions from this work are presented in Chapter 5, as well as the ways in which this work can be developed further.

Chapter 2

Constraining stellar population parameters from narrow band photometric surveys using convolutional neural networks

2.1 Introduction

As summarised in Section 1.2.2, upcoming large-area narrow band photometric surveys, such as Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS), will enable us to observe a large number of galaxies simultaneously and efficiently. However, it will be challenging to analyse the spatially resolved stellar populations of galaxies from such big data to investigate galaxy formation and evolutionary history. Therefore, a computationally efficient method for deriving stellar population parameters from the data is required, and will become invaluable in the future with larger surveys producing increasing volumes of data.

In this chapter, we present neural networks as a tool that shows promise in overcoming this challenge. This chapter is a proof of concept study, investigating whether neural networks can be used to derive the age and metallicity parameters of galactic stellar populations from narrow-band-photometric data. We also examine how the accuracy of predictions of age and metallicity gradients, compared to

those derived directly from the spectra, depend on the training set use in the neural network.

In Section 2.2, the synthesis of the data is discussed. **Analysis of CALIFA data and generation of the synthetic mock J-PAS data were undertaken by P. Sánchez-Blázquez. Based on the information provided by P. Sánchez-Blázquez, the description of these data and methodology in this section were written by C.L. Liew-Cain.** This is followed by the methodology of the neural network and gradient analysis in Section 2.3. Section 2.4 presents the results of our neural network model. Summary and conclusions for this work are provided in Chapter 5. **Sections 2.3, 2.4 and the conclusions were completed by C. L. Liew-Cain.** The content of this chapter is based on the work found in Liew-Cain et al. (2021).

2.2 Data

In order to test the effectiveness of a neural network model in recovering age and metallicity from a narrow-band photometric survey, we construct J-PAS-like narrow band filter data, i.e. 'mock J-PAS data', from Calar Alto Legacy Integral Field Area (CALIFA) integral field unit (IFU) spectra. We then assume that the spectroscopically derived ages and metallicities from the CALIFA data are the true values for each spectrum within each galaxy. The training and testing datasets for our neural network are composed of the mock J-PAS data and the spectroscopically derived age and metallicity.

In Section 2.2.1 we explain the CALIFA data, and in Section 2.2.2 we describe how we make the synthesised J-PAS data from the CALIFA spectra. These data were provided by Patricia Sánchez-Blázquez.

2.2.1 CALIFA

Galactic spectra from the CALIFA survey (for more information about the CALIFA sample see Sánchez et al., 2012; Walcher et al., 2014) are binned **to make the signal-to-noise ratio (SNR) consistent which is required for accurate results from spectral fitting**, and the code Gas AND Absorption Line Fitting (GANDALF

Sarzi et al., 2006) is applied to them. GANDALF simultaneously fits the absorption and emission lines, treating the latter as additional Gaussians. In the first step, emission lines are masked and the absorption line spectrum is fitted as the penalized pixel-fitting PPXF (Cappellari, Emsellem, 2004), using the stellar population models of Vazdekis et al. (2010) as templates. In this step, radial velocities and absorption line broadening for the stellar components were derived. The best values of velocity, broadening and template mix are then used as initial values for the calculation of emission lines. The fit allows for fitting low order Legendre polynomials to account for small differences in the continuum shape between the pixel spectra and the templates. Emission lines were subtracted from the observed spectra before extracting their star formation histories. **Gaussian models were chosen to model the spectral lines because the primary lines identified for the fitting could be appropriately modelled by them, including the effects of stellar kinematics.**

Star formation histories were derived using the code STEllar Content and Kinematics via Maximum A Posteriori likelihood (STECMAP, Ocvirk et al., 2006) on the emission line-cleaned spectra as described above, with the MILES stellar library (Sánchez-Blázquez et al., 2006), a Kroupa Universal Initial Mass Function (Kroupa, 2001) and Padova 2000 (Girardi et al., 2000) isochrones, which cover a range of ages and metallicities from 63 Myr to 17.8 Gyr and $-2.32 <$[Z/H]$< +0.2$, respectively (for a detailed description of the procedure see Sánchez-Blázquez et al., 2014). **As described in Ocvirk et al. (2006) and Sanchez-Blazquez et al. (2011, 2014), STECMAP identifies the best fit star formation history and age-metallicity relation by comparing the observed spectra across the whole wavelength range with the synthesised spectra from the different star formation histories and age-metallicity relations.** No cosmological priors were applied when the values for the ages of the stellar populations were determined. This means that the ages of the galaxies are allowed to be, in principle, higher than the age of the Universe. In a number of cases, we also run STECKMAP and mask the position of the emission lines instead of subtracting them, obtaining the same results (the differences in the mean values of ages and metallicities is lower than the random

errors due to the noise of the spectra).

We have decided to use IFU data as it is the most suitable for radial gradient analysis of galaxies. IFU data allows better spatial averaging of galactic properties than long slit instruments. The sample used in this analysis, taken from Sánchez-Blázquez et al. (2014), comprises a total of 190 galaxies with high enough quality data to compute age and metallicity. Of this sample, 44 galaxies are early-type galaxies and 146 are late-types according to their classification on the SIMBAD database (Wenger et al., 2000). This is not representative of the full CALIFA sample (Walcher et al., 2014) which contains a significantly higher fraction of elliptical galaxies. **From the star formation history and age – metallicity relation derived with STECKMAP, we calculate a mean luminosity weighted age and metallicity for each spectrum in the dataset using spectral fitting (see equation 50 of Sánchez-Blázquez et al., 2014).** Any spectra whose fit was deemed to be poor (i.e. with reduced $\chi^2 > 2$) were ignored for this work, giving a dataset composed of 19,727 spectra.

2.2.2 Synthesised J-PAS data

J-PAS is a multiband photometric survey which runs at the Observatoro Astrofisico de Javalambre in Spain, with a 3.89 m^2 collecting mirror. The J-PAS instrument covers a 4.7 square degrees per observation, with a pixel size of 0.456 arcsec. The effective integration time is 4.96 hours per field (Benitez et al., 2014).

The response curve of the 54 narrow-band filters are spaced 100 Å apart with a FWHM of 145 Å, covering the range of $3785 - 9100$ Å. The magnitude limit is $21.0 < m_{AB} < 25.7$ mag, and varies by filters. These narrow band filters act as a low-resolution spectrograph, with an effective resolution of 100 Å (compared to CALIFA's resolution of 2Å) and are able to detect the broad galaxy emission features.

The synthetic photometry was obtained by convolving each **CALIFA** spectrum with the response function of the J-PAS filters. **These mock-SEDs and the corresponding age and metallicity values derived from spectral analysis were used as the dataset for the convolutional neural network.** As the spectral range

of CALIFA is 3700-7000 Å, we only measured 36 J-PAS magnitudes. We further exclude the two bands JPAS-6600 and JPAS-6700 to avoid being affected by the possible presence of the Hα emission line. An example of the generated mock J-PAS SED and the original CALIFA spectrum can be seen in Fig. 2.1, where the red line shows the mock J-PAS SED. The black curve shows the full, cleaned CALIFA spectrum. The lack of absorption line features in the narrow band SED has previously made the determination of age and metallicity significantly more challenging for photometric instruments compared to spectral surveys.

The determination of ages and metallicities using broad-band wavelengths is difficult due to the similar variations in the shape of the continuum caused by an increase of both parameters (the so-called age-metallicity degeneracy Worthey, 1994). Individual absorption lines are also affected by this problem, but each line has a different sensitivity to variations of age vs metallicity and, therefore, if we measure several lines we can alleviate the problem.

However, the usefulness of narrow-band photometry to derive stellar population properties has not been sufficiently explored. These magnitudes are much more sensitive to the strength of absorption lines than broader bands and they can be measured with a much larger SNR than the absorption lines. A derivation of age and metallicity using medium-band photometry from the Advanced Large Homogeneous Area Medium Band Redshift Astronomical (ALHAMBRA) survey was presented in Díaz-García et al. (2015). This study showed that age and metallicity can be measured with a rms uncertainty of 0.10 dex and 0.16 dex, respectively.

The increased number of J-PAS bands, compared to those of ALHAMBRA, mean that we have more information available to circumvent large errors caused by the age-metallicity degeneracy. The age-metallicity degeneracy is caused by many spectral features responding in similar ways when the stellar population's age changes compared to when the stellar population's metallicity changes. This makes it difficult to determine accurate ages and metallicities using these spectral features. Instead, spectral features which are more sensitive to either age or metallicity (Worthey, 1994) should be used to accurately determine stellar population ages and
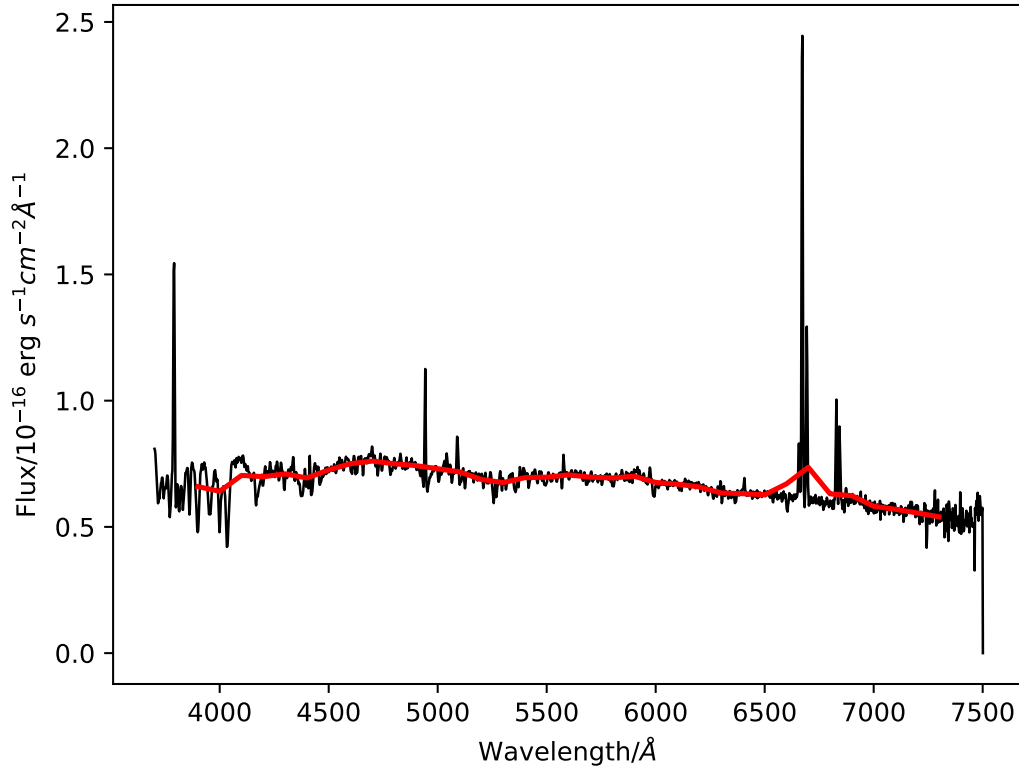
Figure 2.1: A comparison of the spectral curve given by CALIFA (black) and the simulated J-PAS response (red) for one spectrum in NGC2530. The majority of spectral lines cannot be seen in the J-PAS SED, making it more difficult to extract age and metallicity information.

metallicities.

Using spectral energy distribution (SED) fitting to the Sloan Digital Sky Survey (SDSS) spectroscopy data and the J-PAS mock data created from the spectroscopy data, Mejía-Narváez et al. (2017) demonstrated that the age and metallicities of the galaxies can be obtained from the J-PAS data as accurately as from the spectroscopy data. Our work is motivated by their study showing promising results that J-PAS-like narrow band data contain some information to break the age and metallicity degeneracies in a similar degree to the spectroscopy data. Hence, it would be interesting to explore if the neural network can learn such information and provide the accurate age and metallicity much faster than traditional methods.

2.3 Method

2.3.1 Neural network

We use supervised neural networks to predict the metallicity and age of a sample of galaxies from their J-PAS-like SEDs (see Section 2.2.2 for details on their synthesis) with the Tensorflow *Keras* API (Abadi et al., 2015)[1]. The determination of age and metallicity are treated as a regression problem. The convolutional neural network (CNN) we develop uses the spectroscopic age and metallicity derived by CALIFA as the "true" value for the purposes of training. Each of the neurons in the network begins with some randomized weight, and the simulated magnitudes for each band pass through the CNN to calculate a predicted value for the age or metallicity. The mean squared error of predicted versus spectroscopic age or metallicity is back propagated through the network to adjust the weights of the neurons. This process is repeated to obtain an accurate output.

The CNN used in this chapter has an architecture as illustrated in Fig. 2.2. The starting point for the CNN was taken from Fabbro et al. (2018), who used a CNN to analyse stellar spectra. Our chosen architecture has two convolutional layers, a max pooling layer and two dense layers. The 1D convolutional layers capture patterns and multi-filter features across the SED. The max pooling layer then reduces the dimensions of the convolutional layers' output. This is applied to the classical dense neural network layers which calculate the age or metallicity via non-linear combinations of values given by the outputs of the max pooling layer. **We experimented with architectures containing 1, 2 and 3 dense layers and found that models with 2 dense layers provide the most accurate predictions for both the age and metallicity of our data; the robust standard deviation of predictions with 2 dense layers was lower than that for 1 or 3 layers. Increasing the number of dense layers beyond this would have significantly increased the training time required.** The age and metallicity for each of Set A and Set B (see section 2.3.2) were determined by separate CNN models, which had identical architectures but

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[1] See `https://github.com/ChoongLing/SimulatedJ-PAS` for the code used for the methods discussed in this section.

CNN Parameters			{filters, kernel size}		Pool size	Neurons	
	Set A	Age	{40, 12}	{60, 10}	5	40	35
		Z	{8, 6}	{55, 10}	4	30	40
	Set B	Age	{50, 8}	{33, 12}	8	25	30
		Z	{25, 8}	{20, 10}	6	30	35
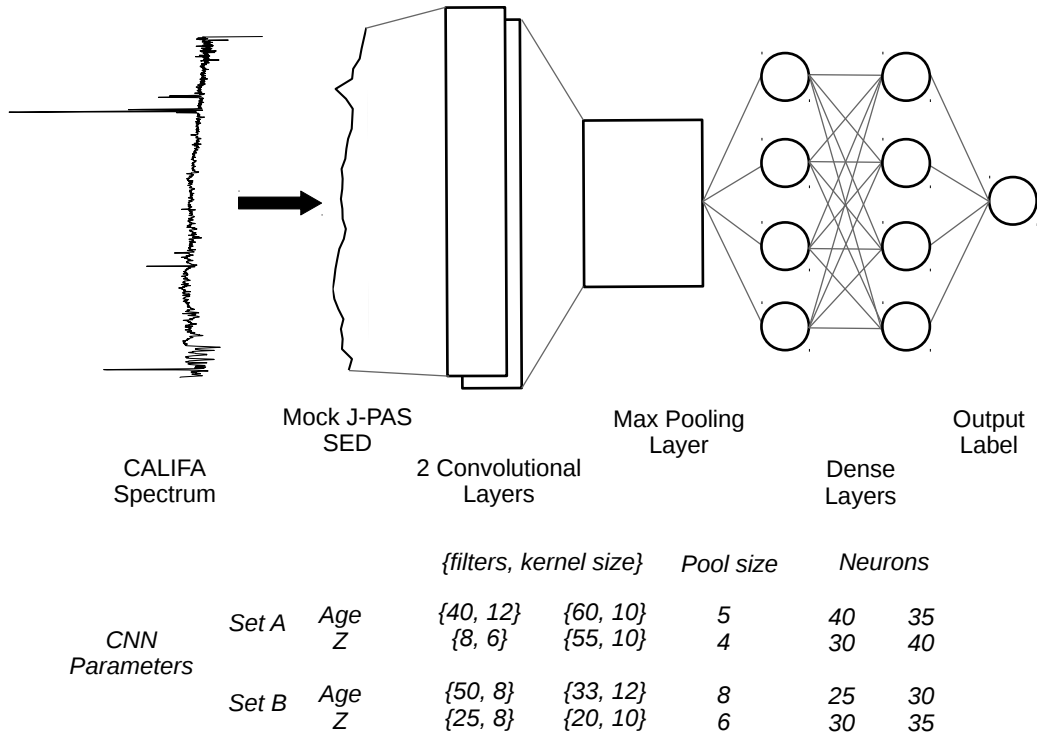
Figure 2.2: A schematic view of the architecture used for the convolutional neural net-
work (CNN). The CALIFA spectra are converted into mock J-PAS photo-SED,
which are then passed through two convolutional layers. A max pooling layer
reduces dimensionality, and its results are passed through a single dense layer.
The predicted value of age or metallicity is then output by the CNN. The hy-
perparameters used for our CNNs are shown at the bottom of this figure.

different hyperparameters, which are shown at the bottom of Fig. 2.2. The layers'
hyperparameters were optimised by Hyperas[2]. Comparisons showed that the set
of hyperparameters chosen by Hyperas provide more accurate predictions than are
made by CNNs with manually chosen hyperparameters.

We also adopted early stopping with a patience parameter of 25 for the CNN.
This meant that if there was no improvement in the mean squared error (MSE) of the
parameter recovery after 25 epochs, training would stop. The CNN would train for
a maximum of 5000 epochs or until the MSE stabilised. A total of 19,727 spectra
from 190 of galaxies was used in this analysis.

To train the neural network to predict metallicity and age for the full dataset,

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[2]https://github.com/maxpumperla/hyperas

25% of the data was kept aside for the testing of the trained CNN to produce our results. The other three quarters was used for training the CNN. This process was repeated three more times so that metallicity and age predictions were made for the full dataset, with each iteration using a training set independent of the unseen testing set. Our final results are given by single realisations of the trained CNN models. The randomness in predictions is taken into account when gradients are calculated (see sections 2.4.2 and 2.4.3) but not for individual predictions. This is because we do not have values for the errors of our spectroscopically determined ages and metallicities, and therefore we could not properly estimate the uncertainties of the model prediction, for example through using Bayesian Neural Networks (e.g. Ciucă et al., 2021). Additionally, our CNNs are not designed or trained to handle noise. Although evaluating the uncertainties of individual predictions is important, it is beyond the scope of this study, because the aim of this proof of concept study is to demonstrate the ability of CNNs to extract age and metallicity data from narrow band spectra.

2.3.2 Defining the Training and Testing Sets

Two ways of splitting the dataset into four subsets are explored in this study, which are illustrated in Fig. 2.3. The first is by splitting the spectra within each galaxy randomly into the four subsets, ensuring that one quarter of the data from each galaxy are put into each one of the four subsets. The CNN is then trained on three of the four subsets, with the final subset kept aside and unseen for testing. This will be referred to as Set A. The other method, Set B, is created by randomly splitting the 190 galaxies into four subsets, with all of the spectra from one galaxy in the same subset. This means that the testing set for Set B contains galaxies which have not been seen at all by the CNN during training. The key difference is that in Set A the training set contains spectral data from every galaxy, therefore the training and testing datasets are not completely independent due to the covariance between adjacent spectra.

It is possible that spectra from the same galaxy will have similar stellar and chemical evolution histories, even at different positions within the galaxy. In this

way, Set A mimics a situation where a large number of galaxies are included in the training set, which will cover the diversity in galactic evolutionary history, so that the training set contains data from similar galaxies to those in the application set. Set B demonstrates the realistic case, where we do not have any previous knowledge about a galaxy in the testing set. In this proof of concept study, we compare the ideal case of Set A with the realistic case in Set B. Although it is more realistic, Set B suffers due to the relatively small size of our dataset. Conversely, Set A is a suitable way of exploring the potential benefits of a large, comprehensive training dataset. Therefore, this comparison will show the potential of the CNN method when a large dataset becomes available in the future.

2.3.3 Radial Gradient Analysis

Radial gradients for the age and metallicity within the effective (half-light) radius, R_e of the galaxy are also calculated and analysed for both the CNN predictions (Section 2.3.1) and CALIFA spectroscopic age and metallicity. We analysed the gradients only for the galaxies that have at least 25 spectral data points within $R < R_e$ and there is at least one data point at $R > R_e$, to ensure that enough spectra to cover up to $R < R_e$. This allows us to produce reliable radial gradients.

To obtain the gradient, the inclination of each galaxy was corrected to determine the face-on projected radius for the position of each spectrum. A linear fit to age or metallicity against radius was computed using Monte Carlo (MC) bootstrapping to randomly select a sample of 75% of the data. A least squares fit was obtained for 100 MC samples. Then, the mean gradient and its standard deviation were calculated from these samples. This was performed on both the spectroscopic and CNN predicted values, which were then compared. As no uncertainties were computed from the CNN predictions or spectroscopic values, the uncertainty in the gradient fitting was determined by the standard deviation of the MC derived gradients. Therefore, the uncertainties in the linear gradient fitting do not consider any intrinsic uncertainties in the CALIFA spectroscopic analysis or CNN predictions.

Figs. 2.5 **and 2.6** show an example where metallicity and age are plotted against radius for the galaxy NGC 7671 using Set A **and Set B, respectively** (see
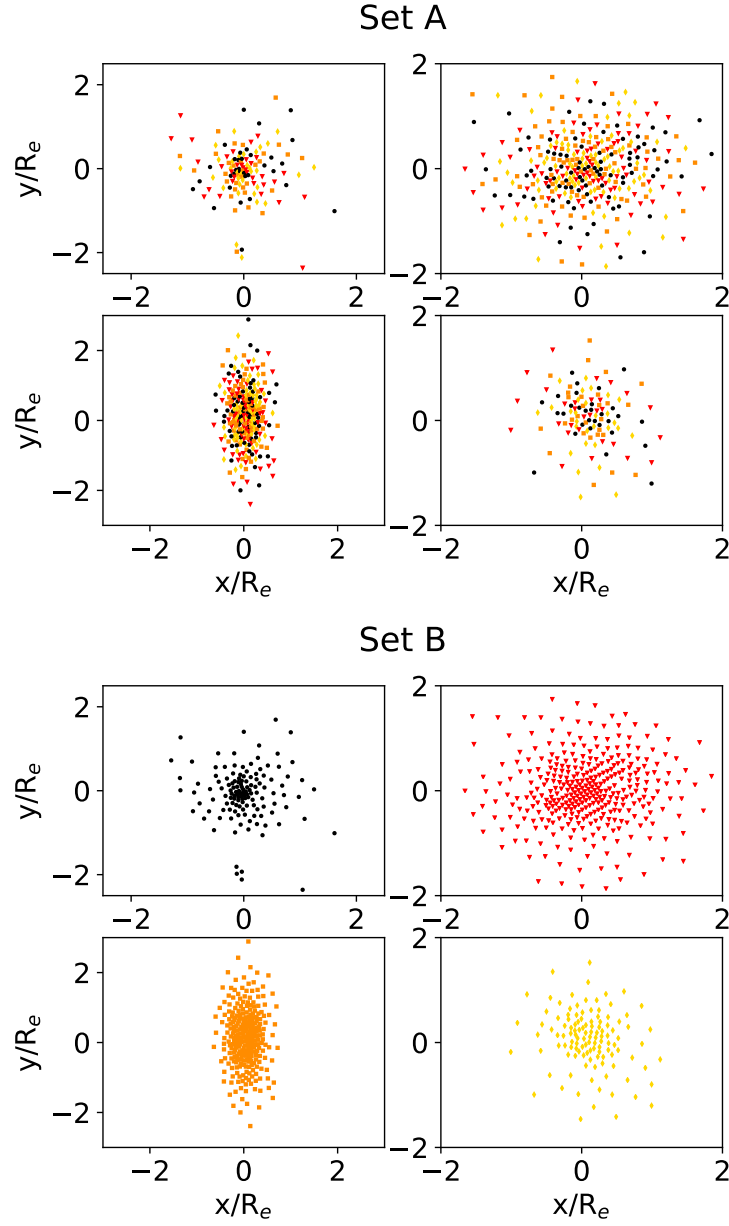
Figure 2.3: Illustrations showing how the spectral data are split into four subsets, as described in Section 2.3.2. The top four panels show the splitting for Set A and the lower four for Set B. In both sets of panels, the spatial distribution of the spectra in four different galaxies are shown. Each spectrum is represented by a coloured shape depending on which subset it belongs to (black circles, red triangles, orange squares or yellow diamonds). In Set A, the spectra within each galaxy are split amongst the four subsets, whereas in Set B all of the spectra for a given galaxy are in the same subset.
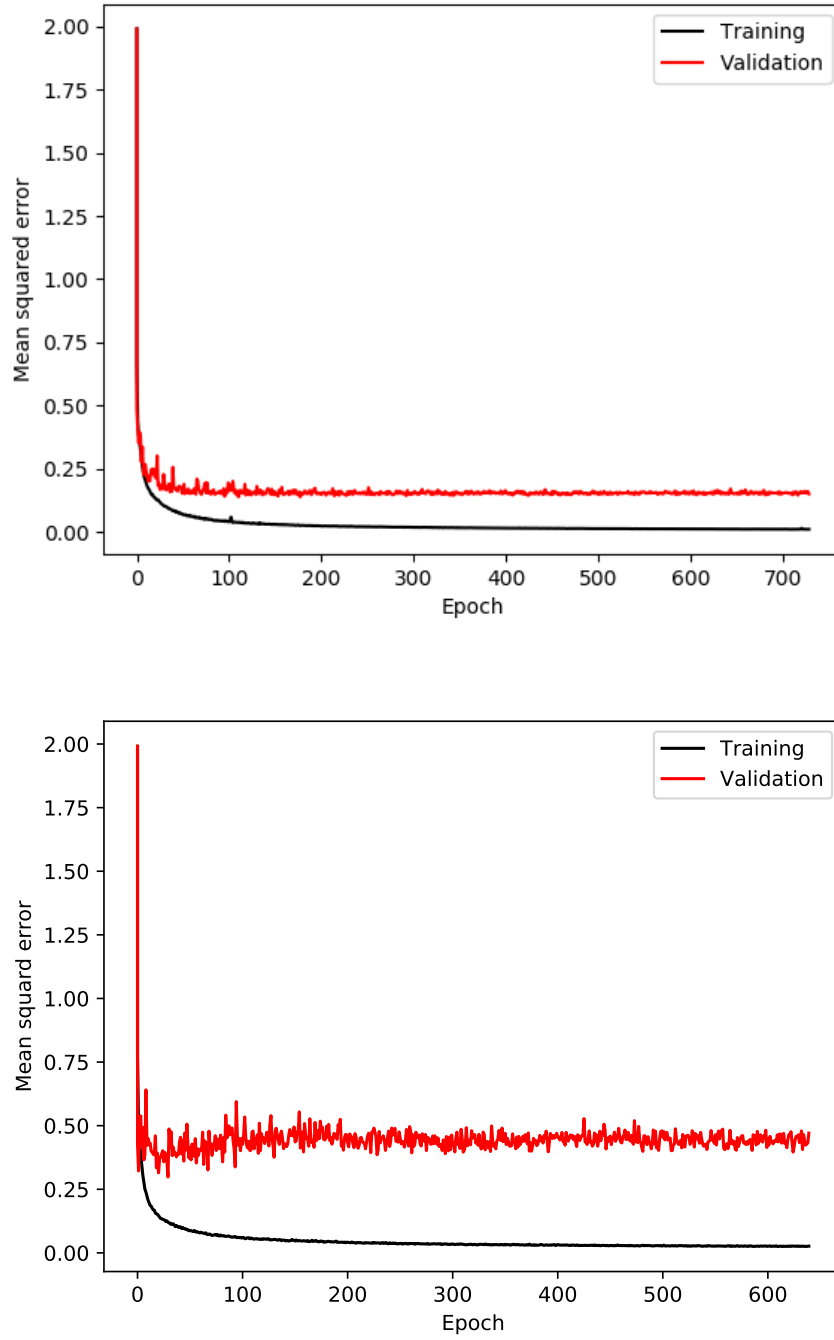
Figure 2.4: Learning curves for the training of one CNN model for the ages of galaxies in Set A (upper) and Set B (lower). The black curve shows the mean squared error (MSE) of the training set and the red curve shows the MSE of the validation set. The initial MSE for the 0th epoch is set as 0.199, which is calculated from a set of random predictions. Early stopping with a patience parameter of 25 was used when training the CNNs.

Section 2.3.2). The top row shows the spectroscopic (i.e. the true label, left) and CNN (predictions, right) metallicity, with the bottom row showing the equivalent diagrams for age. The grey crosses are the values for each spectrum. The red lines show the fits produced by each iteration of the MC bootstrapping. The black line shows the gradient derived from the mean value of the MC fits. **For Set A, the predictions of the CNN are accurate, which can be seen because the locations of the grey crosses are similar to those in the spectroscopic plots. This means that gradients derived from the CNN predictions of age and metallicity will be similar to those derived from spectroscopic analysis. On the other hand, for Set B, the predictions are less accurate, which leads to a greater spread of predicted values of age and metallicity. In turn, this leads to less accurate gradients derived, which can be seen by the greater spread in values from the MC fittings (red lines in Fig. 2.6) and, particularly in the case of the age gradient, a very different result from the spectroscopic gradient.**

The results of gradient analysis will be discussed in Sections 2.4.2 and 2.4.3. Only the gradients will be discussed in this work.

2.4 Results

Results from Set A will be discussed in Sections 2.4.1 and 2.4.2 and results from Set B will be presented in Section 2.4.3. We investigate the effects of other galactic parameters and training set size on the accuracy of CNN predictions in Section 2.4.4 and Section 2.4.5, respectively. Section 2.4.6 covers the dependence of our radial gradients on stellar mass.

This work is a proof-of-concept study which uses CNNs to reproduce the ages and metallicities derived by Sánchez-Blázquez et al. (2014) using traditional spectral analysis from narrow-band photometric surveys. As such, this work does not contribute more data from which galactic evolutionary histories can be derived. Instead, it illustrates that CNNs are appropriate tools for the accurate analysis of stellar population properties from narrow-band surveys, able to resolve the age-metallicity degeneracy and are not affected by other
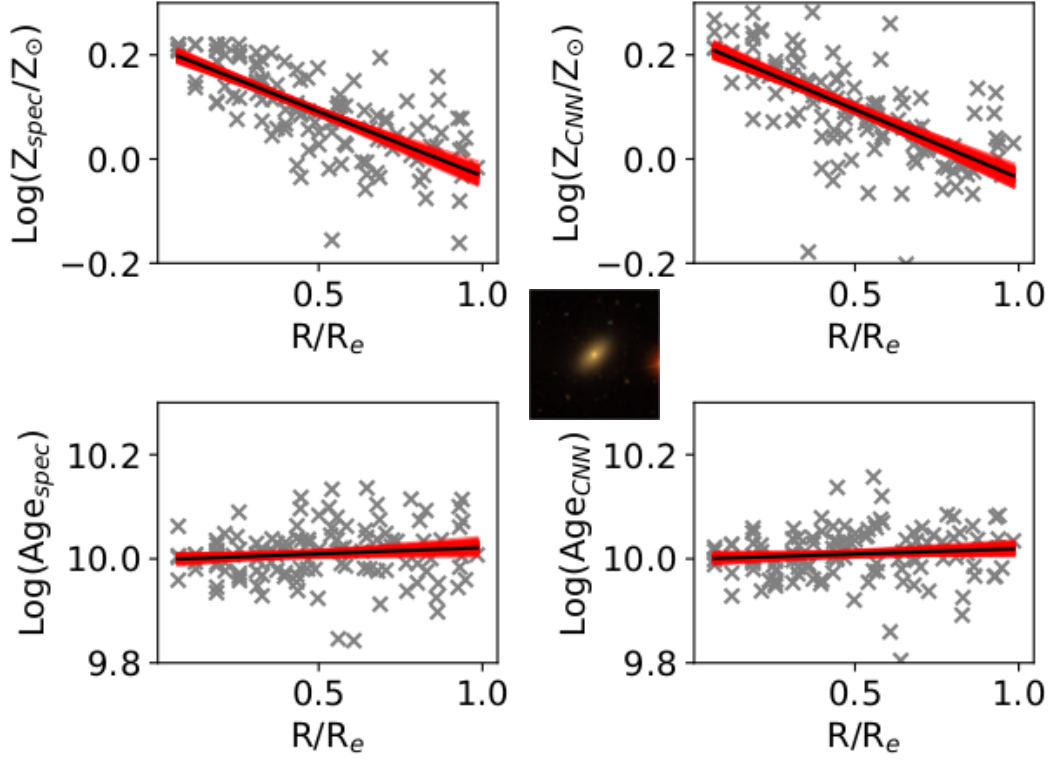
Figure 2.5: The derived spectroscopic and CNN-predicted ages and metallicities against radius for NGC 7671 with a 4'×4' SDSS image embedded in the centre. The CNN trained using Set A (see Section 2.3.2). The top row shows metallicity and the bottom panels display age. The left hand column shows the parameter values derived directly from CALIFA spectra, and the right contains predictions from the CNN. The value of each spectrum is shown as grey crosses. The linear fits to these data computed by 100 iterations of MC bootstrapping are shown as red lines, with the mean values for these fits plotted as the solid black line. **Predictions of individual ages and metallicities are accurate in this case, which leads to similar gradients produced by spectroscopic and CNN analysis.**

galactic parameters including extinction, SFR and inclination. This study also demonstrates that the training set must be very carefully chosen as it can have a large impact on the results of the analysis.

2.4.1 Set A: Predictions of age and metallicity

The recovery of age and metallicity using Set A is shown in Fig. 2.7. The grey points show the prediction of the CNN against the value determined from CALIFA, which we consider to be the true values. A contour map shows the normalised distribution of these points. The solid black line shows a 1:1 correlation, i.e. a
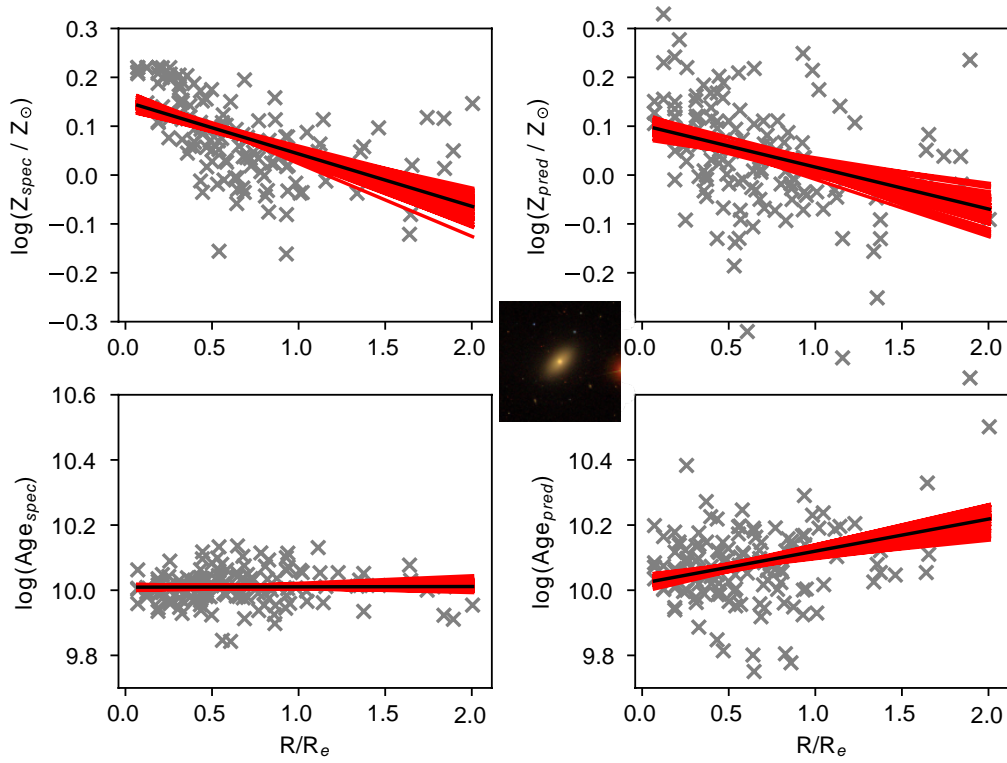
Figure 2.6: **As Fig. 2.5 using Set B data. In this case, the prediction of individual SED values of age and metallicity are less accurate than in Set A. This leads to a greater uncertainty in the errors derived (shown by the larger spread of red lines) and, especially in the case of age, very different gradients derived.**

CNN prediction that is identical to the spectroscopic value. The recovery here is excellent, which can be seen as most points lie close to the 1:1 recovery line. The robust standard deviation (calculated from the median absolute deviation) of the difference between CNN and spectroscopic values for Set A are 0.03 for both age and metallicity. These uncertainties are epistemic, i.e the difference between the spectroscopic and predicted values, showing how well our CNN model is able to reproduce the spectroscopically determined values from the given set of synthetic fluxes (see Hüllermeier, Waegeman, 2019, for more information). Therefore, the fact that our uncertainties here are lower than the statistical uncertainties reported elsewhere (e.g. Sánchez-Blázquez et al., 2014) is not concerning as these errors represent different effects.

This level of accuracy in reproducing age and metallicity is encouraging, and

shows that the CNN is working well. Once the model has been trained, its application to the test dataset is very rapid, meaning it is suitable for use in the large datasets, such as those that will be produced by J-PAS. The standard deviation in the CNN predictions is comparable to those obtained by CALIFA spectral fitting (e.g. Sánchez-Blázquez et al., 2014). The value of the Pearson's Correlation Coefficient (PCC) between the age and metallicity residuals of the CNN prediction and the spectroscopic values is $r = -0.24$ which shows a weak negative correlation between the two predictions. This shows that our CNN models make predictions that are no more affected by the age-metallicity degeneracy than the values obtained with a full spectral fitting.

2.4.2   Set A: Gradient analysis

The values of age and metallicity from each point – both spectral and CNN predicted – are used to calculate a radial gradient, as described in Section 2.3.3. The differences between the CNN predicted and spectroscopic gradients are plotted in Fig. 2.8. The black crosses show the difference between the calculated gradients, with the red lines showing 1-σ error bars computed using the MC bootstrap sampling. The top and right panels show histograms of the difference between the gradients of metallicity and age, respectively, with bins of 0.05 dex/R_e. There is strong clustering of the differences in gradient in the central 0.1 dex/R_e. The gradient recovery is found to be accurate to within a robust standard deviation of 0.02 dex/R_e for both age and metallicity. It can also be seen that there is no clear correlation between the age and metallicity gradient deviations of the CNN values from the spectroscopic gradients, which shows that the quality of CNN predictions are not affected by the age-metallicity degeneracy.

2.4.3   Set B: Age and metallicity prediction and gradient analysis

The recovery of age and metallicity for Set B is shown in Fig. 2.9. The contour levels are the same as in Fig. 2.7. The epistemic robust standard deviations in this case are 0.16 dex for both age and metallicity with a PCC of the residuals of $r = -0.24$. This is the same value as the PCC in Set A, and therefore the more
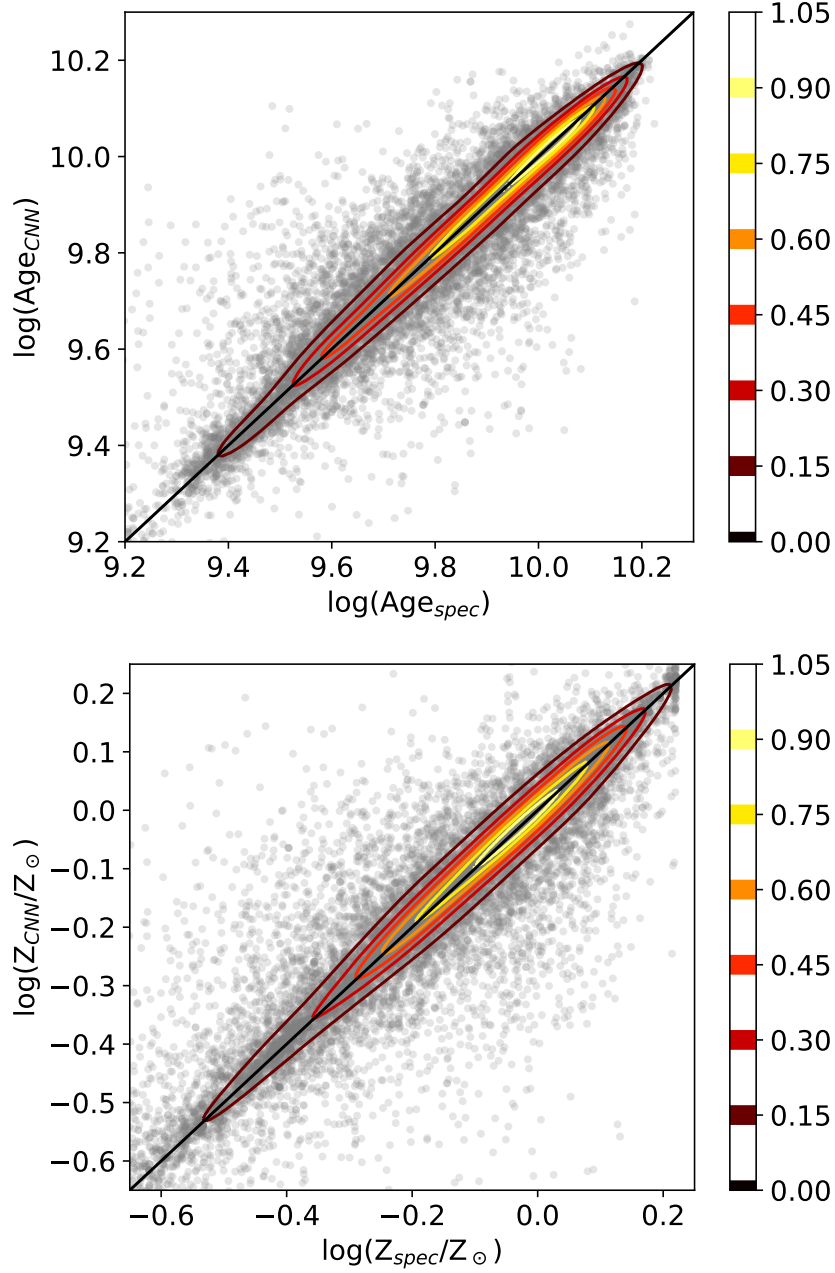
Figure 2.7: The luminosity-weighted age (top, Age$_{CNN}$) and metallicity (top, Z$_{CNN}$) derived from the CNN against the spectroscopically determined age (Age$_q$spec) and metallicity (Z$_{spec}$) for Set A showing only data with a spectroscopically determined value of age and metallicity with reduced $\chi^2 < 2$. The solid black line shows a 1:1 correlation, which corresponds to perfect recovery. The contour map shows the normalised density distributions of the results of the spectra. The CNN values of age and metallicity are consistent with the spectroscopically determined values, with a robust standard deviation of 0.03 dex for both values

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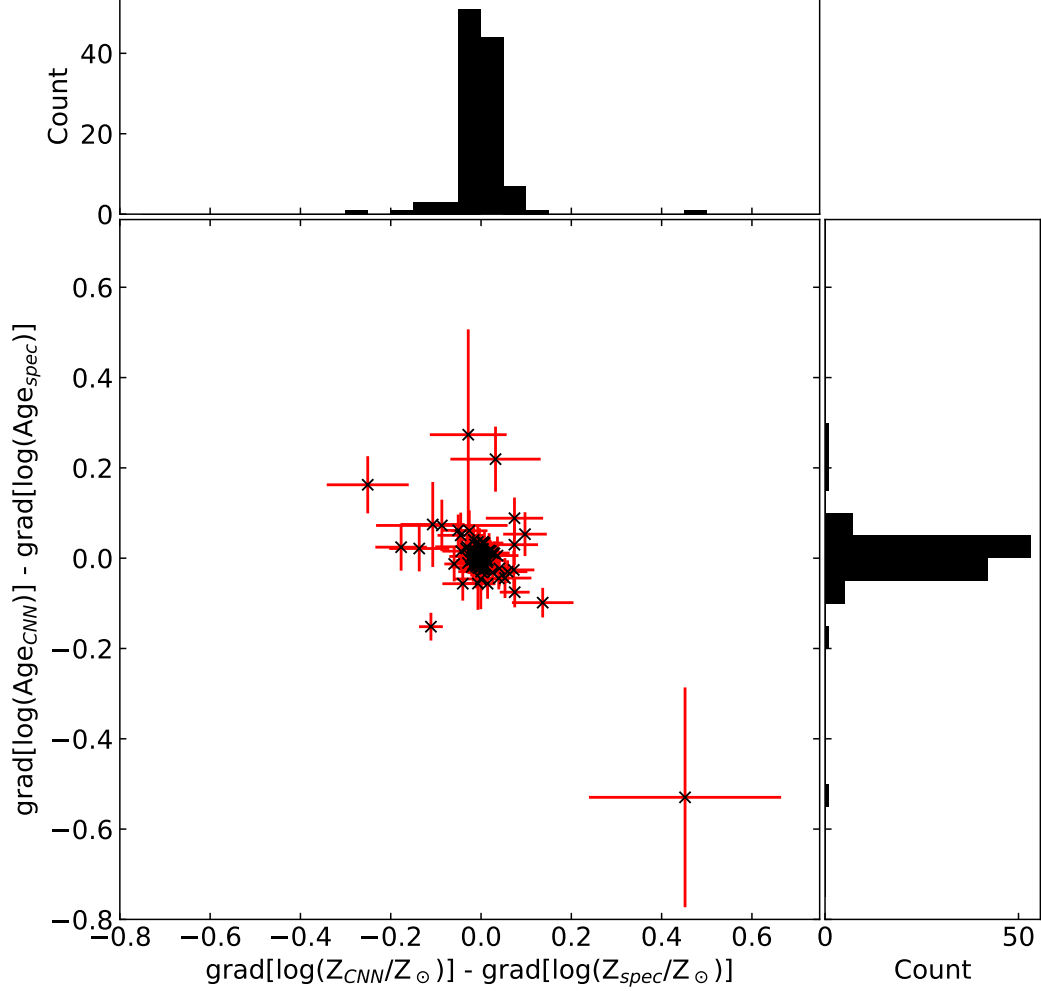
Figure 2.8: The difference between the gradients from CNN predicted age, grad(log(Age$_{CNN}$)), and the spectroscopically derived age, grad(log(Age$_{spec}$)), against the difference in the CNN predicted metallicity gradient, grad(log(Z$_{CNN}$/Z$_\odot$)), and spectroscopically derived metallicity, grad(log(Z$_{spec}$/Z$_\odot$)). Red error bars show 1-σ confidence limits for the gradient fitting. The top and right panels show histograms of the gradient differences in bins of 0.05 dex/R_e . The robust standard deviation for the difference in gradients is 0.02 dex/R_e for both age and metallicity. There is no visible correlation between differences in CNN predictions for age and metallicity gradient and the respective spectroscopic gradients.

independent data used to train our Set B models does not affect the ability of the CNNs to overcome the age-metallicity degeneracy. It can be seen that the contours are much more spread out, and not concentrated around the black 1:1 recovery line. The age recovery, in particular, shows an offset with CNN predictions systematically lower than the spectroscopic values. At lower metallicities, the predictions of the CNN become less accurate, which can be seen as the contours spread further from the black 1:1 line. This effect is likely due to the rarity of spectra with $\log(Z_{spec}/Z_\odot) < -0.75$ in the training set. The use of synthetic spectra or data augmentation (e.g. Ciucă et al., 2021) could improve predictions by creating more training examples for lower metallicity data points and will be considered in future works.

The quality of the CNN's gradient recovery of the spectroscopic values in Set B are displayed in Fig. 2.10. These are markedly worse than the results obtained in Set A. In this case, the standard deviation for gradient recovery, $\mathrm{grad}_{CNN} - \mathrm{grad}_{spec}$, is 0.15 dex/$R_e$ and 0.16 dex/R_e for age and metallicity, respectively. The reason for this discrepancy between Sets A and B is likely due to the diversity in star formation histories among galaxies. The accuracy of Set A implies that the formation history of different regions within the galaxy are similar. As a result, the training set of Set A contains data with similar stellar populations to the testing set, which improved the performance of the CNN. Conversely, the training set for Set B does not contain enough variation to cover the star formation and chemical evolution histories of the unseen galaxies for the CNN to accurately reproduce the spectroscopic values of age and metallicity. This could be resolved in future works by either using a larger dataset or employing synthetic data to increase the diversity of our training set.

2.4.4 Dependence of Predictions on Galactic Parameters

To study the importance of the similarity of stellar populations between the training and testing sets, we explore the dependence of the accuracy of CNN predictions of age and metallicity on specific star formation rate (SFR/M_*), i.e. the total galactic star formation rate divided by its stellar mass.), galactic inclination, extinction (A_V) and galaxy morphology. We also examined the effect of the fractional size of the
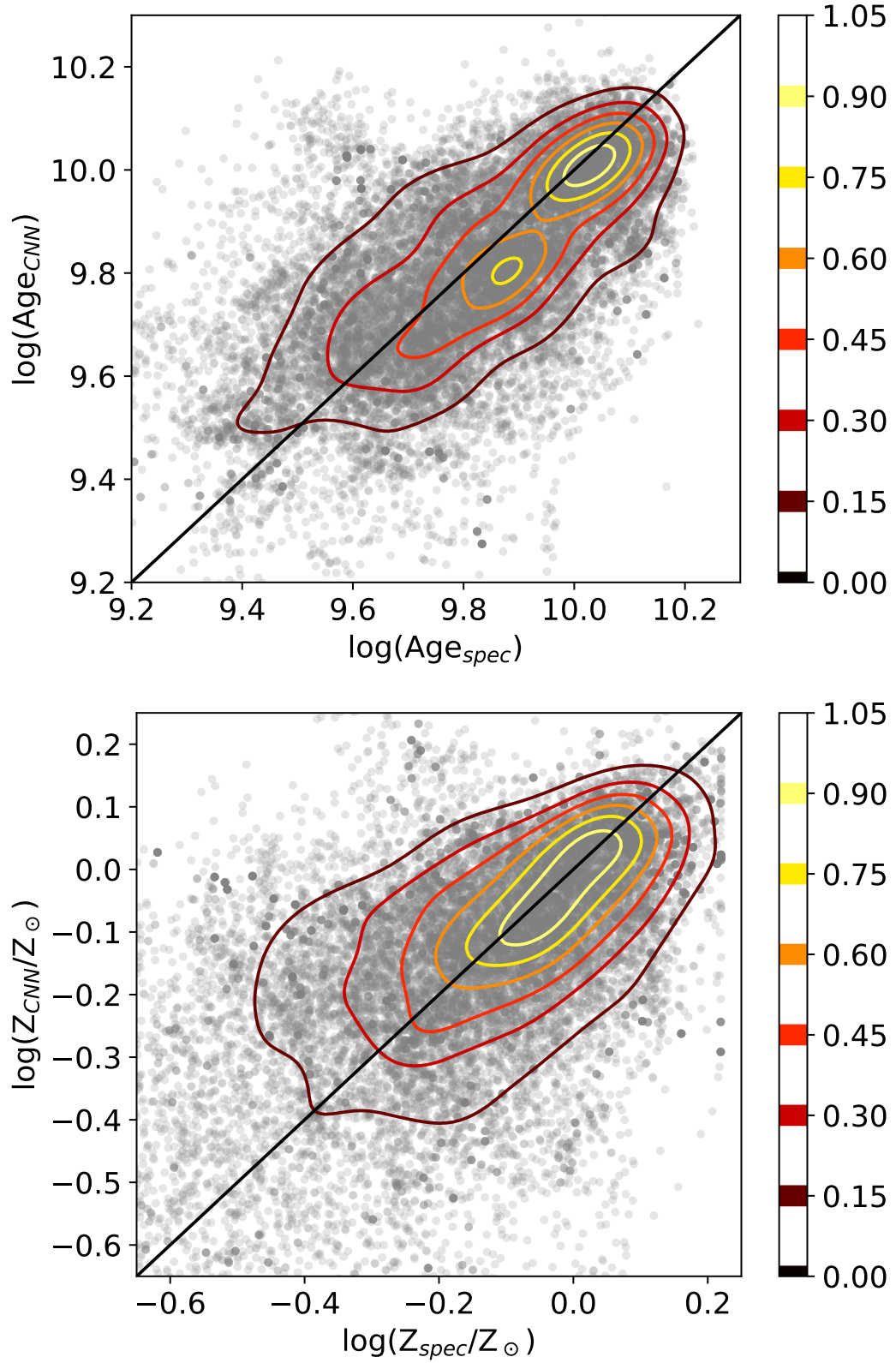
Figure 2.9: The luminosity-weighted age (Age$_{CNN}$, upper panel) and metallicity (Z$_{CNN}$, lower panel) derived from the CNN against the spectroscopically determined age (Age$_{spec}$) and metallicity (Z$_{spec}$) for Set B. Recovery here is significantly worse than in Set A, with robust standard deviation of 0.14 dex and 0.16 dex for age and metallicity, respectively

.
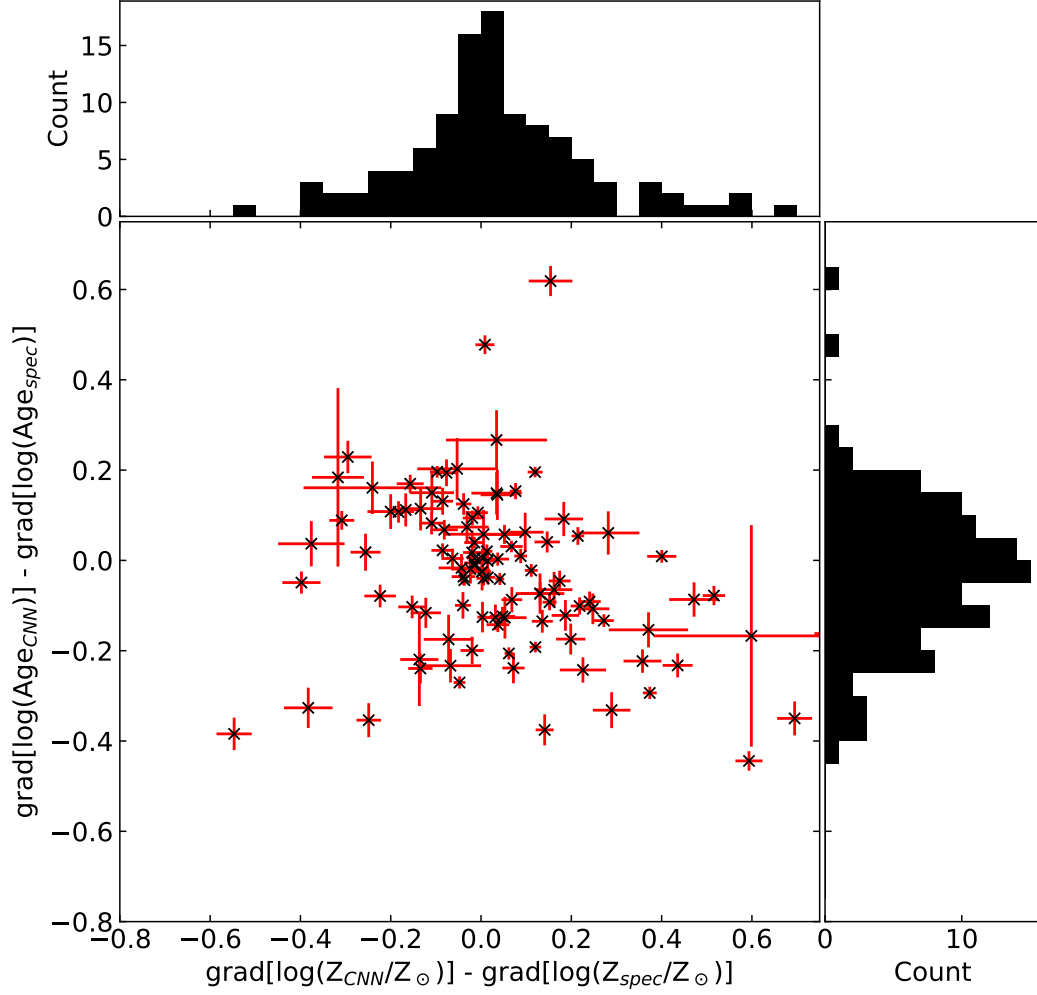
Figure 2.10: The difference between the gradients from CNN predicted age, grad(log(Age$_{CNN}$)), and the spectroscopically derived age, grad(log(Age$_{spec}$)), against the difference in metallicity gradient from the CNN, grad(log(Z$_{CNN}$/Z$_\odot$)), and spectroscopically derived metallicity, grad(log(Z$_{spec}$/Z$_\odot$)) for Set B. The recovery in Set B is much worse than Set A, with robust standard deviation increased to 0.15 dex/R_e and 0.16 dex/R_e for age and metallicity, respectively.

galactic bulge on the accuracy of our predictions but found that there was no visible correlation.

The median and robust standard deviation of the difference between the CNN predictions and spectroscopically derived values are computed from each SED within the galaxy. In Figs. 2.11, 2.12 and 2.13 the median values for each galaxy are shown in the left column of the figures. The robust standard deviations for each galaxy are given in the right columns. Each of these values are plotted against specific SFR, inclination and A_V in Figs. 2.11, 2.12 and 2.13, respectively. The upper four panels in each figure show the results of Set A, while the lower four panels show the results of Set B. The first and third row of panels for each set corresponds to the metallicity and the second and fourth rows correspond to age.

In Fig. 2.11, it can be seen that the robust standard deviation for accuracy of predictions of age and metallicity slightly increases with specific SFR. However, this is not reflected in the median values. Additionally, there is no visible trend in either median or robust standard deviation of predictions with inclination (Fig. 2.12) or extinction (Fig. 2.13), which shows that our CNN models are not affected severely by these galactic properties.

The 190 galaxies in our sample were split by morphology (taken from the SIMBAD database, Wenger et al., 2000) giving 44 early-type galaxies and 146 late-type galaxies. CNNs were trained on 33 of the elliptical galaxies and 114 spiral galaxies, respectively using the method for Set B, as in Section 2.4.3 . These CNNs were then applied separately to the remaining galaxies in each morphology set.

The robust standard deviations for the differences between spectroscopic and CNN predicted values are given in Table 2.1. It can be seen that predictions for the ages of each of the morphology groups are more accurate when the CNN has been trained on the same morphology group. Additionally, when the CNN has been trained on only early-type galaxies, the age prediction performs best for early-type galaxies and has a robust standard deviation of 0.10 dex. Prediction of the age and metallicity of late-type galaxies are of similar quality regardless of whether the CNN is trained on early- or late-type galaxies. This is unexpected, but is likely due
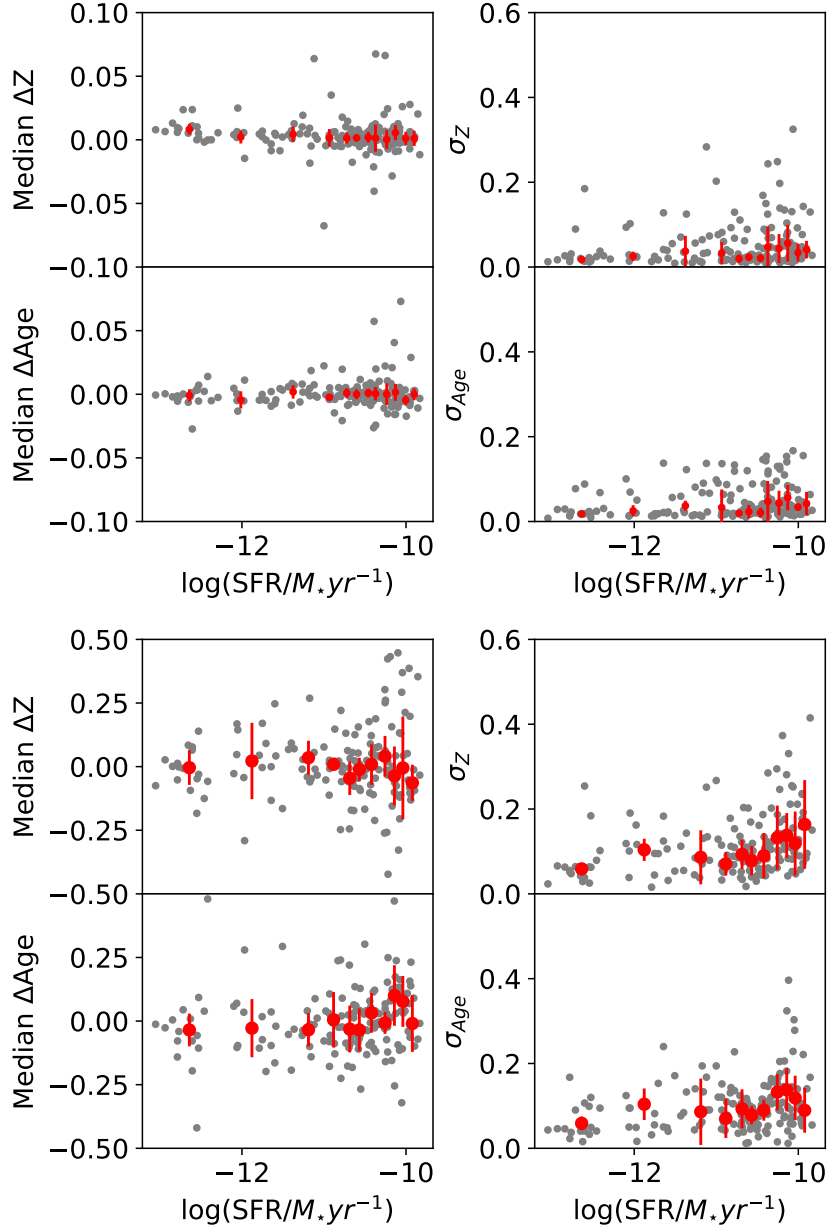
Figure 2.11: The dependence of the accuracy of predictions on specific star formation rate (SFR) for Set A (upper four panels) and Set B (lower four panels). The left column shows the median value of the difference between CNN predictions and spectroscopic values of age (median[$\log(Age_{CNN}) - \log(Age_{spec})$], 2nd and bottom row) and metallicity (median[$\log(Z_{CNN}/Z_{\odot}) - \log(Z_{spec}/Z_{\odot})$], first and third rows). The right column shows the robust standard deviation of the difference between CNN predictions and spectroscopically determined values. The grey dots show the median and robust standard deviation computed from the results of different SEDs for each galaxy's age or metallicity against specific SFR. The red dots show the median of bins of 16 galaxies and the error bars show the robust standard deviation of the bin. It can be seen that the uncertainty of the predictions increases slightly with specific SFR, though the median values do not show such a dependence. Note the *y*-axis for the median differences of Set A has been reduced by a factor of 5 due to the significant difference in accuracy.
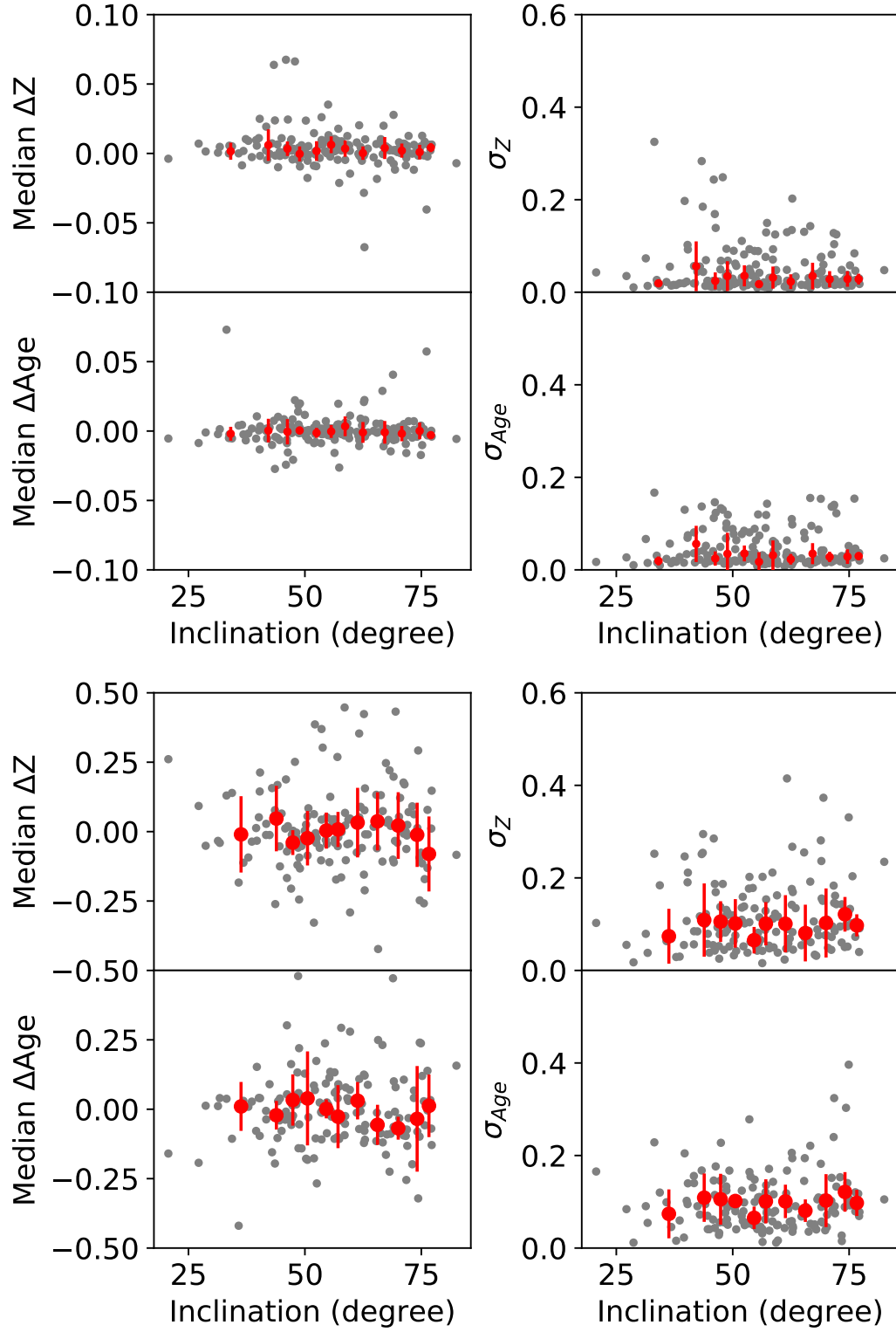
Figure 2.12: As in Fig. 2.11 but plotted against inclination. The inclination has been adjusted to be between 0 and 90 degrees.
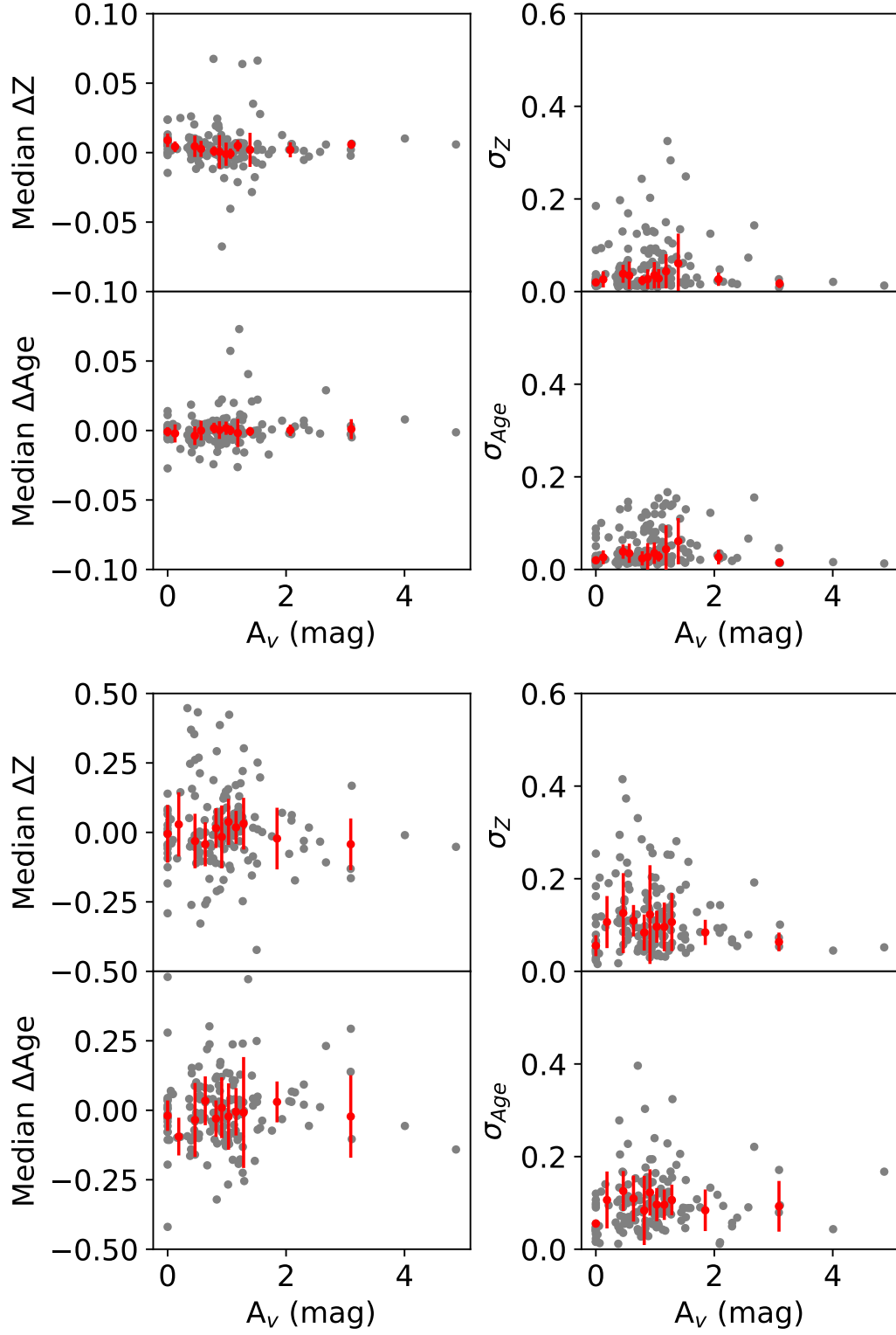
Figure 2.13: As in Fig. 2.11 but plotted against extinction, A_V. There does not appear to be any correlation between the accuracy of predictions and the extinction.

Age		Training Set		
		Early-types	Late-types	Full set
Appl Set	Early-types	0.10	0.14	
	Late-types	0.16	0.15	
	Full set			0.14

Z		Training Set		
		Early-types	Late-types	Full Set
Appl Set	Early-types	0.12	0.13	
	Late-types	0.19	0.17	
	Full set			0.16

Table 2.1: The robust standard deviations of the difference between spectroscopic and CNN predicted age (upper) and metallicity (lower table) defining the training and application sets as for Set B (see Section 2.4.3). The columns indicate whether the CNN was trained on early- or late-type galaxies, and the rows indicate whether the application set (appl set) set was composed of early-type or late-type galaxies. The uncertainty for the full set, as derived in Section 2.4.3, is given in the third row and column of each table for comparison. See the text for more information.

to the presence of similar stellar populations between early-type galaxies and the bulges of late-type galaxies. Overall, the recovery of early-type galactic properties is significantly better than the full dataset for Set B, whose values are shown in the third row and column of each table, but is still worse than for Set A. We believe that the increased accuracy in recovery of early-type galaxies is due to the greater degree of similarity between the stellar populations found in early-types than between late-types. This supports our conclusion that the CNN is more capable of predicting age and metallicity values for stellar populations similar to those present in the training set. Therefore, a larger, high-quality dataset would be crucial for future deep learning analysis of stellar populations.

2.4.5 Training set size

The size of the training set is very important in neural networks. Typically, very large datasets are used in analysis using CNNs. This is because a large volume of data increases the accuracy of neural network predictions. In this section, we discuss the impact of how the size of the training set affects the predictions of our CNN model, though we are still limited by our relatively small dataset.

Fig. 2.14 shows the robust standard deviation of the difference between spec-

troscopic and CNN predicted age values for Set A (solid lines) and Set B (dashed lines) as a function of the training set size, given as a fraction of the total size of the dataset. Note that we only used the results for data points whose spectroscopic values are reliable (i.e. with reduced $\chi^2 < 2$), to evaluate the performance when the CNN model is applied to the similar quality data to the training set. Training and application of the CNN model was performed 100 times with randomly selected training and application sets for each iteration. The standard deviation for the recovery of age was recorded for each model, and the mean and uncertainty of these standard deviations is shown in Fig 2.14. The horizontal red dotted line shows the standard deviation we would expect if the predictions were made by simply choosing a random value from the set of spectroscopic ages. Both Set A and Set B results are below this line, which confirms that the CNN learned some relation to map the input features to the output values better than picking a random value from the training set.

The accuracy of recovery of Set B decreases as the training set size decreases, and the uncertainty of this accuracy increases. For Set A, the decrease in the accuracy of recovery between 5% and 75% is $\sim 1\sigma$ therefore it is not statistically significant. Despite the increase in prediction accuracy for Set B, the recovery in Set A with a training set of 5% of the total dataset is ~ 0.07 dex smaller than the recovery of ages in Set B using 75% of the dataset. This supports our conclusion that increasing the number of galaxies in our dataset to account for the diversity in star formation histories is crucial in increasing the accuracy of CNN predictions. In other words, the number and diversity of the spectroscopic data used in this chapter is not enough for accurate recovery of stellar population parameters from a testing set composed of galaxies that are not included in the training set. We would expect that with data from more galaxies with a diverse range of star formation histories, either real or simulated, we would see the prediction accuracy for Set A to improve with increasing sample set size, as seen in Set B in Fig. 2.14. In addition, we expect that the accuracy of the recovery for Set B, when using a large training set, would approach that of Set A.
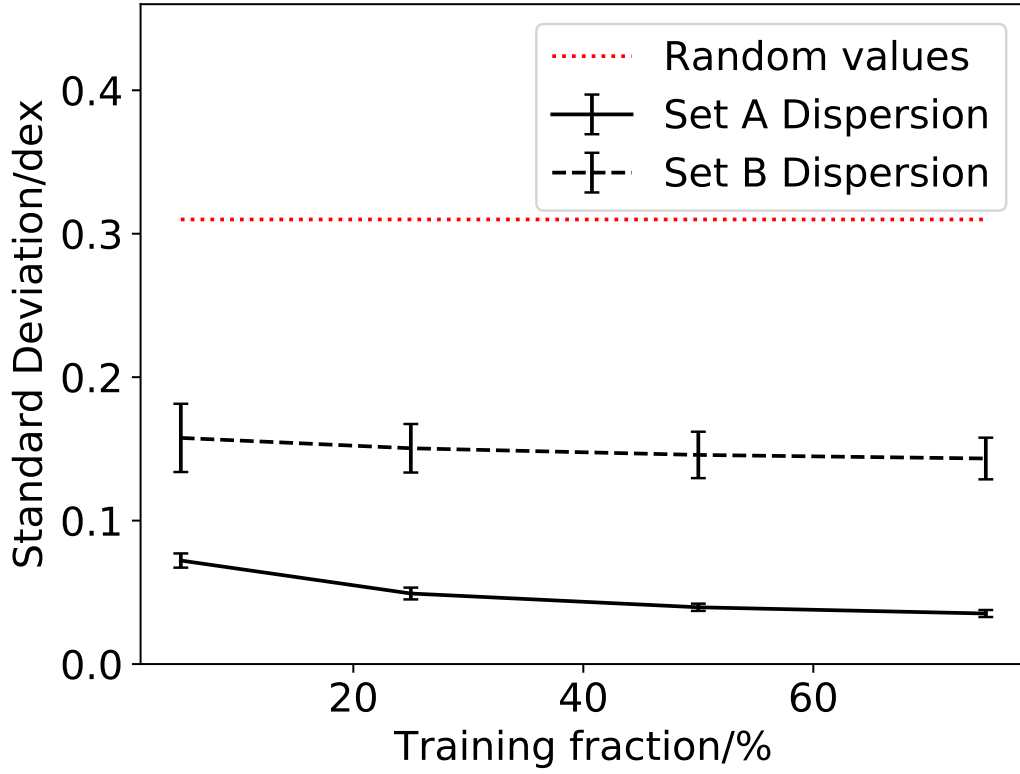
Figure 2.14: The variation in standard deviation of CNN recovery of age values as a function of the size of the training set is varied. The training set varied between 14795 (75% of the full dataset) and 986 (5%) SEDs for Set A (solid line). Training with Set B uses between 157 galaxies (75%) and 10 galaxies (5%) (dashed line). The red dotted line shows the standard deviation we would expect if the predictions were made by simply choosing a random value from the set of spectroscopic ages.

These findings imply that the stellar populations in different regions within the same galaxy are significantly more similar than stellar populations in different galaxies with the same age and metallicity. Therefore, in order to use CNNs to predict the age and metallicity in a galaxy, we require a very large training dataset, covering the full parameter space of stellar population properties.

2.4.6 Mass dependence of radial gradients

The dependence of age gradients on galactic stellar mass is of interest when evaluating how galaxies evolve. The relationships we have found between these quantities are shown in Fig. 2.15. The left panel in this figure shows the gradients derived from the spectroscopically measured age. The relationship of the late-type (black
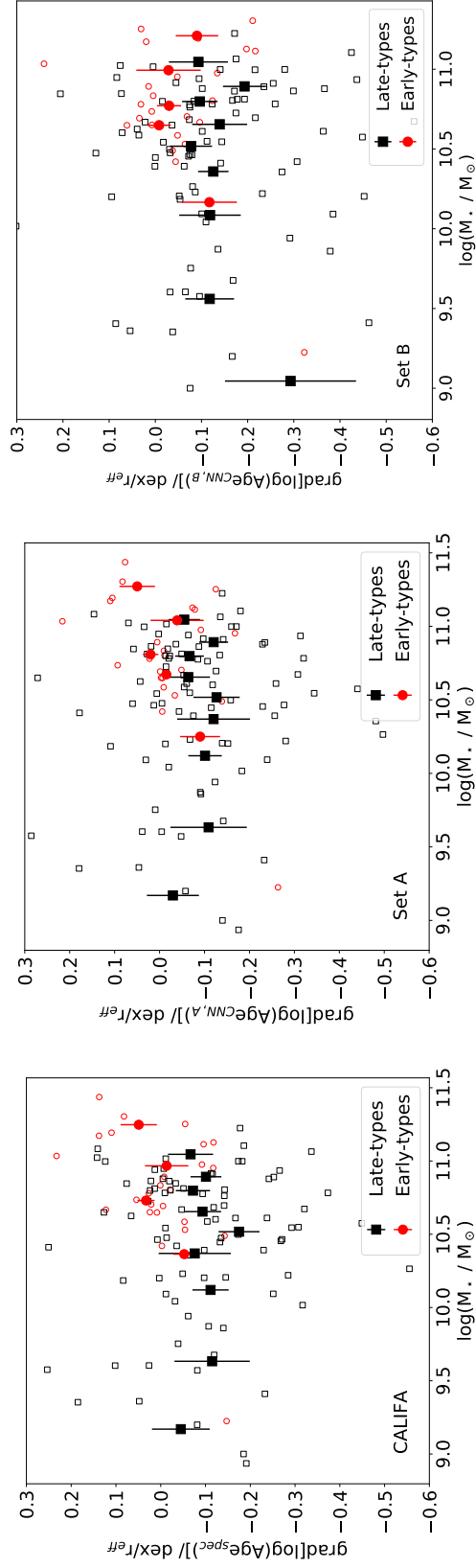
Figure 2.15: The radial age gradient for a galaxy against its stellar mass, using spectroscopically determined gradients from CALIFA (left), and the gradients calculated from CNN predictions with Set A (middle) and Set B (right). The open red circles (open black squares) show the values for individual early- (late-) type galaxies. The filled red circles (filled black squares) show the mean value for each bin of 6 (10) galaxies for early- (late-) type galaxies, with error bars showing the standard deviation. This demonstrates the gradients of Set A are more similar to the spectral gradients than those of Set B.

squares) galaxies' age gradients on mass resembles that of Fig. 6 from Sánchez-Blázquez et al. (2014), that uses the same spectroscopically derived age values as this chapter. This demonstrates that our method of gradient derivation provides results consistent with those of the previous work **in the literature**. It can be seen that the gradients produced by our analysis from Set A (central panel) is similar to that of the gradients derived from spectral values (left panel) and therefore showing similar trends to Sánchez-Blázquez et al. (2014). Conversely, Set B (right panel) shows significant differences from the gradients calculated from the spectroscopically derived age (left panel), which can be seen in both the medians for stellar mass bins (filled symbols) and the derived gradient for individual galaxies (open symbols). **We believe that this is due to the less accurate prediction of individual SEDs in Set B, which is discussed in Sec 2.3.3 and Fig. 2.6.**

The mass dependence of age gradients for a variety of galactic morphologies was studied in González Delgado et al. (2015). In Fig. 10 of their paper, the early type galaxies show higher values of the age gradient in the higher mass galaxies at $\log(M_*) \gtrsim 10.5$. The late-type galaxies show similar trends in the same mass range, but show systematically lower gradient than the early-type galaxies. Then, at $\log(M_*) \lesssim 10.5$ the gradient values become larger for the smaller mass galaxies in the late-type galaxies. These trends are qualitatively reproduced in the left panel of Fig. 2.15. **This is encouraging as it shows that our results are qualitatively similar to those in the literature.** However, the values of the gradients we derived here are systematically higher than those in González Delgado et al. (2015). This could be due to the differing methods of gradient derivation or differences in stellar population modelling (see González Delgado et al., 2015, for details).

Chapter 3

Co-creating an Astronomy-Based Skills Course with Jobseekers

3.1 Introduction

Astronomy has many impacts on everyday life (Fabian, 2010), and has been shown to be more accessible than other areas of science to groups that do not consider themselves as scientists (Smith, 2003). **The accessibility of astronomy visual and phenomenological nature of the subject, as well as humanity's curiosity and desire to explore. Astronomy has also played a part in culture historically[1] and in the modern day.**

As discussed in Section 1.4, we believe that astronomy will prove to be a useful vehicle to engage non-traditional audiences with science. Other research has shown that a lay audience is more likely to take part in scientific research if the subject covered is related to the person's goals, interests and everyday life (Dreyer et al., 2021). Therefore, combining the accessibility of astronomy with the goal of developing skills that could help to find employment would make a course that is engaging and attractive to jobseekers. **This work was completed by Choong Ling Liew-Cain with the exception of Figs. 3.1 and 3.2 which were created by R. Baskeyfield of A New Direction.**

We chose to work with people looking for employment with this study as we

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[1]Section 1.1.1, `https://www.iau.org/public/themes/astronomy_in_everyday_life/`

believed its aims align well with their needs and will be valuable for them. Additionally, jobseekers are a group underserved and not often targeted by public engagement schemes (for similar reasons to students in vocational training in Humm, Schrögel, 2020). We used a co-creation methodology to create an accessible course that develops skills and astronomical concepts of interest to our participants.

In this chapter, we present how we started working with people looking for employment in the cultural sector in Section 3.2. The set up and results of the survey and co-creation workshop are presenting in Sections 3.3 and 3.4, respectively. We discuss the implications of our findings and further work in Section 3.5. Our concluding remarks of this study are found in Chapter 5.

3.2 Project Strategy

3.2.1 Overview

The aim of this study was to produce a workshop to develop skills that jobseekers find useful, and to use the areas of astronomy that they are interested in as an inspirational context for this development. We worked with alumni of A New Direction (AND), a London-based charity who work to help people find employment in the arts and cultural sectors. We designed and ran a survey to collect qualitative and quantitative data from former jobseekers about what they would have liked to learn in a skills-related employment course, their science capital, attitudes towards astronomy and science, and their demographics. After that, we ran a co-creation workshop where we worked with a smaller number of AND alumni to gather qualitative data on more focused questions about developing a course informed by our findings.

From the findings of this co-creation workshop we drew a series of recommendations which can be used to develop a course. In Section 2.1 of Pompea, Russo (2020) a description of the role of astronomers includes the need to "use the excitement that astronomy engenders to increase public understanding of science and scientific methods" and to "capitalize on the close involvement with astronomy, technology, and instrumentation to contribute to training the technical workforce".

We designed our course with these two aims in particular in mind, and hoped to develop both of these aspects within our participants.

We wanted to work with people who had been through a situation similar to those we were creating this course for. Therefore, we targeted AND's alumni as they are all an "expert of their experience" (Visser et al., 2005) and have already had relevant experiences we wish to understand. By working with people with the experience we want to draw on, we targeted areas of this course to aspects that would best work for our participants. This means our course better suits the participants' needs and will be more effective in developing the desired skills.

We designed and ran an anonymous survey to collect some initial information about the participants to inform the options we gave in the co-creation session. We made the survey concise and completable in 10 minutes to increase the number of answers we received. The survey had a wider reach than the co-creation session, so that we could collect data from more people and get a better understanding of what the larger community would like from a skills-based astronomy course. We also asked questions to assess the level of astronomy knowledge and interest to inform the course's content and appropriateness.

To design the course, we used some of the ideas presented in Young, Perović (2016), which describes a method for academics and businesses to design modules for undergraduate courses. These were appropriate for our work because they were developed for use in 90 minute sessions and are suitable for online use. One of the strengths of this method of course design is that it emphasised the use of different types of learning, and to create a balance between types used. This makes our course engaging as there will be an activity that corresponds each person's favoured learning type (Young, Perović, 2016).

We also considered including a problem-based learning approach which has been shown as an effective way to teach astronomy (e.g. Rafelski et al., 2010; Kautsch et al., 2021). However, it would be difficult to include at this stage. Firstly, a problem-based learning project would go into some depth in an astronomy topic and we were not sure which topics appeal to our participants. Secondly, problem-

based learning is time consuming to do within a session. We want to keep our sessions relatively short to make them more accessible so we would have to do this project over multiple sessions. Finding the best way to engage our participants is beyond the scope of this work, though we intend to explore problem-based learning in future work.

There are a variety of methods that could be used to engage with the participating alumni. One of the methods we considered was participatory appraisal. Whilst participatory appraisal can be very effective it takes a long time to do successfully[2]. We chose to use a co-creation methodology because it is an equitable way to work with AND's alumni (Porter, 1998) and allowed the creation of a resource in a relatively short amount of time where everybody had equal voice and input. Co-creation programmes tend to have lower dropout rates due to the visible effect of participants' views and agency given to them (Sanchika Campbell, al. et, 2019). Dreyer et al. (2021) found that citizens prefer to be involved in scientific research in ways where their voices can have greater impact on how science proceeds, and Porter (1998) argues that inclusion in the decision-making process, such as through co-creation, helps to improve access to practices and resources.

During the co-creation workshop, we acted as facilitators to focus the discussions to answer questions that would allow us to develop an effective, engaging course. We took on the roles of researchers (people who examine participants' interactions with the course and their insights) and designers (people who create courses and developments based on the participants' feedback) as detailed in Sanders, Stappers (2008). The findings of the co-creation session will be discussed in Section 3.5.2.

3.2.2 Recruitment

We paid attendees of the co-creation session with a £50 gift voucher each, and offer two prizes of £25 gift vouchers as incentive to fill in the survey. We included these in the text of the advertisement, which was distributed along with the graphics

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[2]e.g. `https://www.northumberlandcva.org.uk/files/NESEP_Participatory_Appraisal_Handbook_2014.pdf`

shown in Figures 3.1 and 3.2, created by R. Baskeyfield **of AND. We note that it is unusual practice to include 'UCL Astronomy' in the advert text due to potential bias in the recruited sample and potentially putting people off taking part due to negative academic experiences. However, AND felt it was necessary to have their partner's name in the advert to provide credibility to the workshop as the subject matter is outside the usual scope and expertise of the charity**. Research has shown that offering reimbursement for participants' time in co-production activities can help to overcome barriers[3] to their participation (e.g. Dreyer et al., 2021).

The survey was advertised by AND via their social media, alumni Slack[4] channel and newsletter on 13th September 2021 to reach as wide an audience with relevant experience as possible. For our co-creation event, which was held on 27th September 2021, we started advertising on 13th September 2021 through *A New Direction*'s alumni Slack channel and newsletter. To recruit more people to the session, the advert was shared on A New Direction's social media on 17th September 2021.

The data we collected from the survey participants was anonymous and although the sample size was small we made it impossible to identify individuals. In the co-creation event, the participants' biographies were kept in a private Miro board (see Sec. 3.4.1) so that only attendees were able to view them. We gathered informed consent from the participants for both the survey and co-creation session about how their data would be used.

3.3 Survey

The anonymous survey was designed in three sections: what people would like from a course, science and astronomy and demographics.

As our survey had a larger reach than the co-creation session, we wanted to use it to collect more people's opinions on what would make a good course.

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[3]https://www.yhphnetwork.co.uk/media/2374/breaking-down-barriers-report-scie-2019.pdf

[4]https://slack.com/intl/en-gb/

Figure 3.1: The advert which was sent out to recruit people to take part in the survey. This was shared to A New Direction's networks on 13th September 2021.

This includes quantitative measures of the skills desired by potential participants, barriers to attending the course and the virtual platforms which participants were comfortable using. The latter point was also useful in creating the co-creation session.

In the science and astronomy section, we used a set of questions developed by ASPIRES [5] to indicate the science capital (Archer et al., 2015, see also Section 1.4.2) of our sample. These questions were used to estimate our sample's

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[5]Led by Professor Louise Archer based at Institute of Education, UCL. `https://www.ucl.ac.uk/ioe/departments-and-centres/departments/education-practice-and-society/aspires-research`

Figure 3.2: The advertisement developed to advertise the co-creation session which was sent out via A New Direction's social media.

initial science capital, including their attitude to science in general. We also included some questions about the sample's initial attitude towards astronomy which we could compare with their attitudes to science to test our hypothesis that astronomy is more appealing to this audience than science. These questions also provide a baseline indicator of science capital which could be compared to the results of similar questions at later points in the course and its development.

The demographics questions were included because of the known intersectionality between science capital and some demographics. This allows us

to see if the indicated science capital of our sample demonstrates similar intersectionalities. We also asked questions about participant's highest science qualifications. This was to make sure that the content of the course was set to an appropriate level.

The questions we asked can be found in Appendix A

We collected a total of 16 responses to the questionnaire. We received 14-16 responses to each of the questions we asked.

3.3.1   What participants want from a course

We wanted to find out the content and formatting for a course that would work best for our participants to make our resource as successful as possible in developing their desired skills. Therefore, we included several questions on the survey to ask about various elements of a course which we could include. We asked *"Which skills or knowledge would you be interested in gaining from a course?"* and presented seven options and an "other" option. From the 16 responses, spreadsheet use (11 people; 68.8%) and programming (12 people, 75%) were the most popular technical skills. Collaboration and problem solving (eight people each; 50%) were the most popular interpersonal and intrapersonal skills. These skills are ones that astronomers possess and develop in the course of their work[6], so it will be appropriate to develop these skills in an astronomy-based skills course. Gaining knowledge of astronomy (eight people; 50%) was much more popular than maths (two people; 12.5%). This supports the findings of other studies (e.g DeWitt, Bultitude, 2020; Trotter et al., 2019) which show that astronomy can be appealing to people who do not consider themselves scientists.

14 people responded to the question *"What barriers do you see that could prevent you or other people taking part in an astronomy-based skills workshop?"* Two of these responses discussed accessibility requirements, e.g. hearing and visual impairments, dyslexia and dyspraxia. 11 of the responses mentioned some form of academic intimidation, expressed in responses including "I don't have experience and may find it daunting", "anxiety at having been bad at maths etc at school" and

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[6]`https://www.ucl.ac.uk/mssl/study/phd-opportunities`

"I didn't really learn about astronomy at school or university and would therefore feel a little nervous about joining an astronomy workshop... as someone who works in the arts, I often feel very distant from the world of STEM".

Findings similar to these were noted by the Social Care Institute for Excellence, who found that one of the main barriers to having people take part in co-production was "lack of access to information" and the use of "inaccessible language and jargon"[7]. Two of the responses included a desire for representation among the leaders; one response read "if I can't see myself represented... I and many others who yet again feel overlooked, won't have the desire or motivation to attend." This is similar to the findings of Dreyer et al. (2021) who found that trust in scientists and policymakers' agendas is more likely to make lay people attend co-production or consultation events. Similarly, the authors found that the participants of their policy-based focus groups felt the need to be part of a diverse group in order for their recommendations to be legitimate.

3.3.2 Demographics

We asked questions about the backgrounds of the people answering the surveys. This was so we could understand more about the experiences that this group has been through. These questions were important as this is not a group who interact with astronomers much so there is limited literature available.

Out of the 16 replies we received, 14 people identified as female, one identified as male and one identified as non-binary. **This sample is more female and non-binary dominated than AND's alumni, which is approximately 60% female and non-binary. In** comparison, in 2018 the Institute of Physics (IOP) found that astronomy university students in UK universities were 29% female and 71% male[8]. The IOP survey accounted for non-binary genders but did not report any numbers. Table 3.1 shows the ethnicities that our responders identify as in comparison to UK-based astronomy students[9]. In the IOP survey, "mixed or multiple ethnic

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[7]https://www.yhphnetwork.co.uk/media/2374/breaking-down-barriers-report-scie-2019.pdf

[8]https://www.iop.org/sites/default/files/2020-07/Student-characteristics-2017-18.pdf

Ethnicity	Our participants (%)	2018 UK-Domicile astronomy students (%)
White	19	86
Black, African, Caribbean or Black British	44	1
Mixed or Multiple ethnic groups	12	*
Asian or Asian British	6	6
Other	19	6 *
Unknown	0	1

Table 3.1: A comparison of the ethnic identities of responses to our survey (**16 people**) and those of UK domicile students studying astronomy in 2018 by the Institute of Physics (**2265 people**)[9]. Survey groups (denoted by a *) "Mixed and Multiple ethnic groups" into the "Other" category. We decided not to do this because both of these categories are a significant proportion of our participants. Our participants are significantly more diverse than UK university astronomy students, the latter of which are predominantly white. Since there was concern from the participants about representation among the leaders of the workshop, this is something that needs to be kept in mind.

group" responses were grouped into the "other" category. We can see that in university astronomy students, the vast majority of people identify as white, whereas our participants are more diverse. We found from the survey that representation in the leaders of the session mattered significantly to the participants, as discussed in Section 3.3.1. Therefore we need to be aware of the demographics of the group we are working with when we recruit leaders for the course. Given that a lack of representation has been identified as a barrier to participation in our workshop (see previous section) this is important to consider.

When asked about their levels of education, we found that 12 out of the 16 (75% of) responders have a degree. For comparison, the Queen Elizabeth Olympic Park area, which we were targeting in this work, reports 41.0% of adults living in this area have a higher education degree (ONS, 2011) [9], and from 2009-2014, 49.3% of 18 year-olds in this area started a higher education course[10]. This region

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[9]https://www.ons.gov.uk/employmentandlabourmarket/
peopleinwork/employmentandemployeetypes/articles/
qualificationsandlabourmarketparticipationinenglandandwales/
2014-06-18

[10]https://www.officeforstudents.org.uk/data-and-analysis/
young-participation-by-area/

is in the top 20% of the UK for both the number of adults holding higher education qualifications and number of 18 year-olds starting higher education. **This high proportion of degree holders is consistent with the demographics of AND's audience, as they work with many young people who have struggled with finding employment after obtaining a degree.**

Five of our responders (31.33% of the total) have degrees in a science or engineering related field. However, we also found that GCSEs were the highest level of science qualification for seven people (43.75%) and that two people (12.5%) did not have any science qualifications. This disparity in previous scientific knowledge presented a potential challenge to designing our course, as we will need to make it accessible for the people who do not have any science qualifications while also keeping the interests of those who have a stronger scientific background.

3.3.3 Opinions on science and astronomy

We asked a series of questions about the responders' attitudes to science and astronomy. This served two purposes: firstly was to inform the design of the session to best align with participants' interests in astronomy. Secondly, was to collect the participants' opinions on science and astronomy before the session so we could provide evidence for any change in opinion after the session. As our survey used the word "Astronomy" in the title and in the advertising, it is possible that this has led to some people who have negative views about astronomy and related fields not responding to the survey, creating a positive bias in our results.

We collected 15 responses to the open question *"How do you think that astronomy affects your everyday life?"* Five responses said that they did not know or were not sure. Four referenced astrology in their responses; commenting that astronomy affects their lives through horoscopes or spirituality. This implied an overlap between astronomy and astrology in some of our participants' views, and presented a misconception which could be valuable to explore in the workshop (Smith III et al., 1994). Six responses mentioned observational astronomy, such as seeing the Sun, Moon or stars. There were three comments about how the effect of astronomy for them is through satellites, communication and technology and two references to

climate change. Responders showed a general idea of how their lives are affected by astronomy, but had some misconceptions and limited examples they could reference. This could be a useful area to focus on in our course.

We assessed our sample's attitudes towards astronomy and science using a 5-point Likert Scale (Likert, 1932). We found that generally people were largely interested in both science and astronomy, and that everyone had a neutral or positive interest in astronomy, shown in Fig. 3.3. There were two people who disagreed with the statement *"I am interested in science"*. These people felt neutral towards astronomy. This finding supports our idea that astronomy could be an interesting tool to get people involved in a workshop, but may be due to the use of astronomy in the title as discussed above. We also found that, as shown in Fig. 3.4, there was generally little correlation between how interested people feel in science and how up to date they felt with developments in science. We found that generally our sample were interested in science but were not necessarily up to date with science.

We asked the question *"What is the first word you think of when you see the word 'Astronomy'?"* The 16 replies we received to this question are displayed in the word cloud shown in Fig. 3.5. Words which were mentioned more frequently are displayed in larger text. Many of these words were related to observational astronomy or objects that the participants might have seen with their own eyes, including "stars" and "planets". We saw the association between astronomy and astrology again here, with the words "astrology" and "transcendent" suggested.

3.3.4 Science Capital

We asked questions to estimate the science capital of our survey sample. We compared our findings with those of the Public Attitudes to Science 2019 (PAS) survey (DfBEIS, 2020) by comparing questions which explored similar themes. PAS is a national survey which assesses the general public's involvement, attitudes and relationships to science, both in general and for specific areas of science. PAS published results on only male and female genders, whereas we encouraged our participants to self-define their gender, so non-binary gendered people are not explicitly compared here. Our initial prediction is our audience would have a lower science capital than
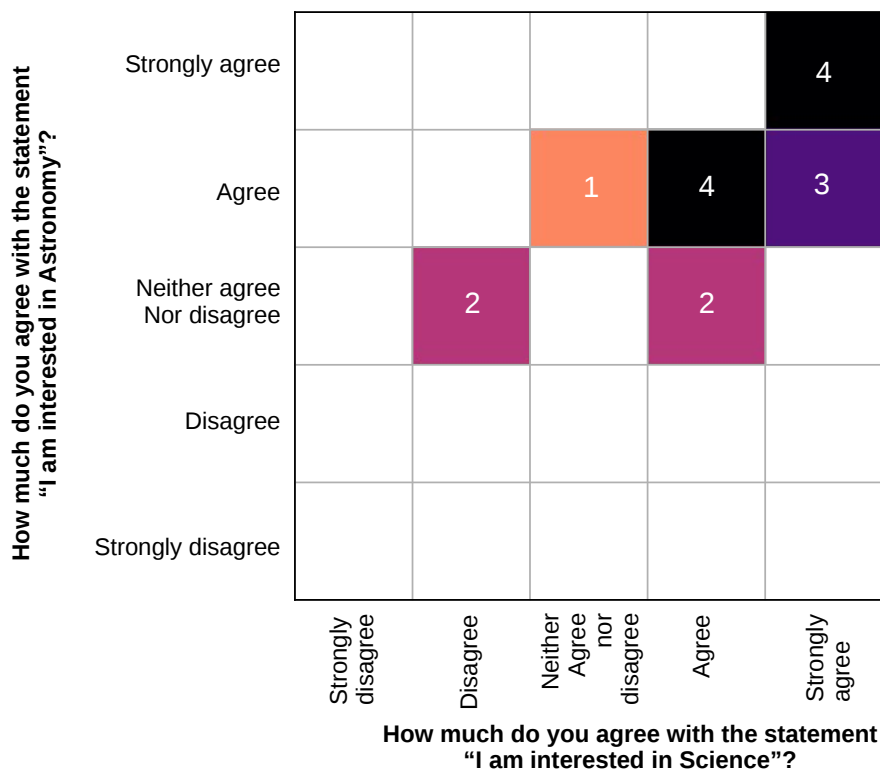
Figure 3.3: A plot comparing interest in science to interest in astronomy. Generally, those who answered the questions are positive about both science and astronomy. Nobody who answered this question responded negatively to astronomy; both of the people who did not feel interested in science were neutral towards astronomy.

the national average **because this group has displayed interest in working in the arts or cultural sectors, which is perceived to be distant and separated from the science sector.**

Both our survey and PAS asked the question *"Do you feel comfortable in science settings?"* and gave examples including laboratories and science centres. We show the results of our findings and the breakdown of PAS in Table 3.2. Our survey's results indicated that our participants were less comfortable in scientific environments than the national average, people who are educated to degree level (as the majority of our participants are) and people aged 16-34, which is the age group A New Direction work with. Our participants showed a similar level of comfort as PAS found women do, which could be because the majority (14/16) of our responses came from women.
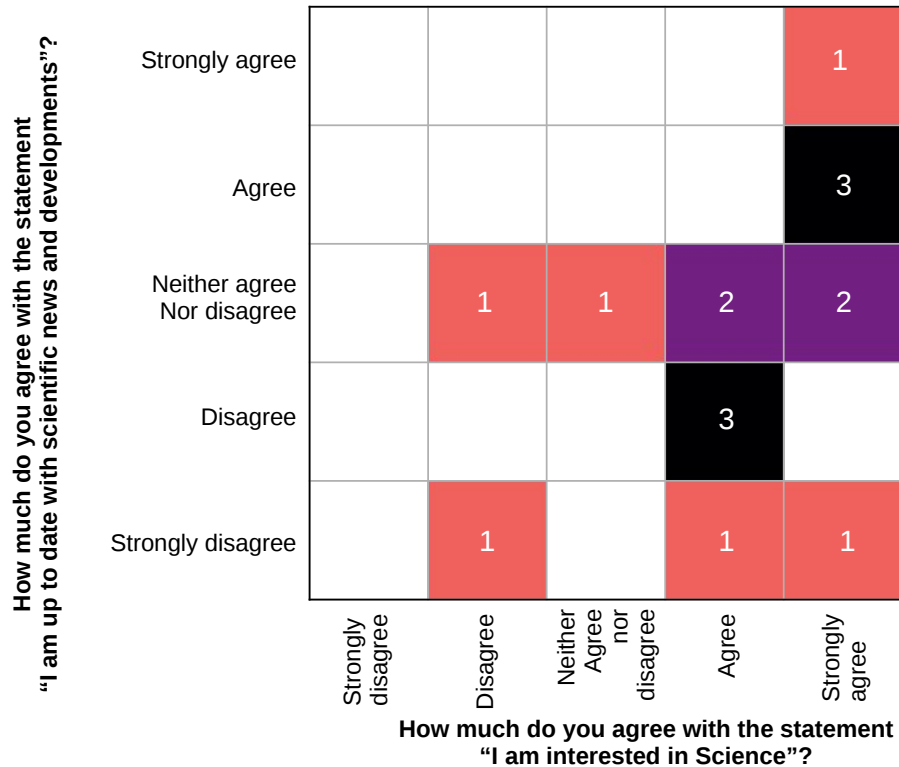
Figure 3.4: A plot comparing interest in science with how up to date people feel with science. The responses indicated that people are interested in science but not up to date, and there is no apparent correlation between the two.

Figure 3.5: A word cloud made of the replies to the survey. Words in a larger font were suggested more frequently than those in smaller fonts. A lot of the answers were to do with observational astronomy, including "stars" and "planets". We saw the association between astronomy and astrology present here.

Both our survey and PAS asked the question *"How often do you talk about science?"* By combining some categories in our survey to match those in PAS, we were able to compare our results with the national average, which is shown in Table 3.3. We found that our participants are more likely to talk about science than the national average, with the modal answer in our survey being "a few times a year" whereas that of PAS is "never". This indicated that our participants had an interest in science, but did not act on their interest to find out more or get involved.

We compared questions between our survey and PAS which covered similar themes. The latter survey found that 51% of people nationally *"feel informed about science"*. This number was 65% for people with degrees and 49% for people without degrees. In our survey, we asked if people *"feel up-to-date with science"*. We found that 25% of responders felt up-to-date and 37% did not. Nationally, 24% of people said that school put them off science. Only one of our participants disagreed with the statement *"I enjoyed science at school"*, but these questions are not easy to compare, as a separate person who agreed that they enjoyed science at school said that they were put off astronomy at school because "it became slightly inaccessible to learn because of the technicalities".

In general, we observed that our participants indicated a lower science capital than the national average and, in some cases, significantly lower than the demographics this group are part of. We saw indications that the group were more interested in science than the national average so using astronomy as a skill development method remains a viable option. Furthermore, we can use the course to support the development of our participants' science capital.

3.4 Co-Creation Session

Eight people attended our 90 minute co-creation session in addition to the five facilitators (C.L. Liew-Cain, B. Littlefield, D. Kawata, R. Baskeyfield and S. S. Sou).

We chose to hold the co-creation session online as spreading Covid-19 was still a large risk at the time it took place. Furthermore, all AND programmes were held online at the time. Online sessions can be beneficial as it removes cer-

	Agree (%)	Disagree (%)
Our findings	50	37.5
National Average	58	29
Men	69	
Women	49	
Degree holders	69	
16-34 year-olds	66	

Table 3.2: The responses to the question *"Do you feel comfortable in science settings?"* **The top row shows the results we found in our work (16 participants), with the other rows displaying the data available in DfBEIS (2020) (1749 participants). "Disagree" data was not provided for demographic breakdowns in this publication.** In general, our participants were less comfortable than the national average, people in their age range and others with degrees. Our participants showed similar levels of comfort to people who identified as female.

	PAS findings (%)	Our findings (%)
Never	32	6.25
A few times a year	19	43.75
Once or twice a month	17	12.5
At least once a week	19	18.75
Nearly every day	13	18.75

Table 3.3: Responses to the question *"How often do you talk about science?"* We found that our participants talk about science more than the national average, which indicated a greater interest in science than the national average

tain accessibility barriers, such as the cost and time of travelling to a venue, and live close captioning software is available which can help people with hearing impairments. However, it can be harder to develop relationships online than in person, and it requires every participant to have access to a device able to run the platforms we used. On the other hand, in-person activities can remove distractions presented by working from home, and create more social opportunities, but can be more difficult for people with certain disabilities or caring responsibilities to attend.

3.4.1 Set-up

For the session, we used Zoom[11] as our video conferencing platform and Miro[12] as our note-taking platform. We separated the workspace on Miro into rectangular

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[11]https://zoom.us/
[12]https://miro.com/

areas for different information or task areas. We refer to these areas as *Miro boards* from here. These spaces gave room for the participants of the co-creation session to write their ideas on virtual sticky notes and place them within the boards to make notes of their discussions and ideas. The choice of platform was informed by consultation of participants in the above survey. The combination of Miro and Zoom enabled participants to contribute by voice or text using their preferred mode of communication and provided a space where all contributions were valued equally. This made our software choices suitable for use in a co-creation session. In addition, we had a designated person during each part of the session who would watch the Zoom chat and could either voice or note on Miro any comments that participants were not able to record themselves.

We included a code of conduct visible on the Miro board, which was also distributed to the participants beforehand so that they knew our policy for contributing respectfully to the session. This improves the equity and accessibility of our session (Favaro et al., 2016). We had a timetable (reproduced in Table 3.4) with links to each of the areas of the Miro board for each of the tasks to make the Miro board easier to navigate. We created three tasks to be completed during the 90-minute co-creation session. Tasks 1 and 2 asked questions about the design and content of a skills-based workshop and astronomy. Task 3 was to co-create a pilot workshop, which will be discussed later. A 10 minute break was included between Tasks 1 and 2.

We had a section for short biographies for each of the participants and facilitators. This was to show that everyone was welcome, their voices was valued equally and they could bring relevant experiences and contributions to the co-creation session. As the survey indicated, and research has shown (e.g. Archer et al., 2021), this helps to make academics more humanised and less intimidating. We also included some time in the session for introductions to make the event more welcoming.

Task 1 was made up of two questions: *"What skills would you liked to have learned when you were working with A New Direction?"* and *"What area(s) of astronomy interest you?"* We had virtual sticky notes with suggestions next to the

13:00-13:15	Introduction and Icebreaker
13:15-13:25	Task 1 – Discussion: *"What skills would you like to have learned when you were working with A New Direction?"* and *"What area(s) of astronomy are you interested in?"*
13:25-13:35	Feedback and free discussion
13:35-13:45	Break
13:45-13:50	Task 2 – Discussion: *"What makes a good workshop?"*
13:50-14:05	Feedback and free discussion
14:05-14:25	Task 3 – Workshop design
14:25-14:30	Final thoughts

Table 3.4: The timetable for our co-creation session.

task to get the conversation moving. These were populated by the results of the questionnaire. We also left some virtual sticky notes around the side blank. These were a visible indicator and space for participants to contribute their own topics and to make it easier for people who were not familiar with Miro to contribute their ideas. The prepared board for Task 1 is shown in Fig. 3.6.

During this task, we split the participants into two breakout rooms in Zoom and duplicated the task in Miro. Splitting the group was to make sure that everyone had time to share their ideas during the task. We decided to use separate Miro areas to avoid any confusion between the two breakout rooms over what was being said in their room, and to observe if there were any large differences between the groups' discussions.

In Task 2 we asked the question *"What makes a good workshop?"* This was to inform the structure and methodology of our workshop. Similarly to the previous task, we had both filled and blank virtual sticky notes prepared on the Miro board for suggestions. During the break in the session, which was just before this task, all participants were sent a Zoom poll to ask if they would prefer to complete this task in a breakout room or as one group. The group voted to use breakout rooms.

The final task was to create a 90-minute workshop based on our aim of teaching skills through astronomy, drawing on the answers that they found particularly relevant from Tasks 1 and 2. **We chose a workshop as the output as AND's courses are delivered through workshops, and so the group of alumni we were working with would be familiar with this format.** The area of the board for Task 3 was set
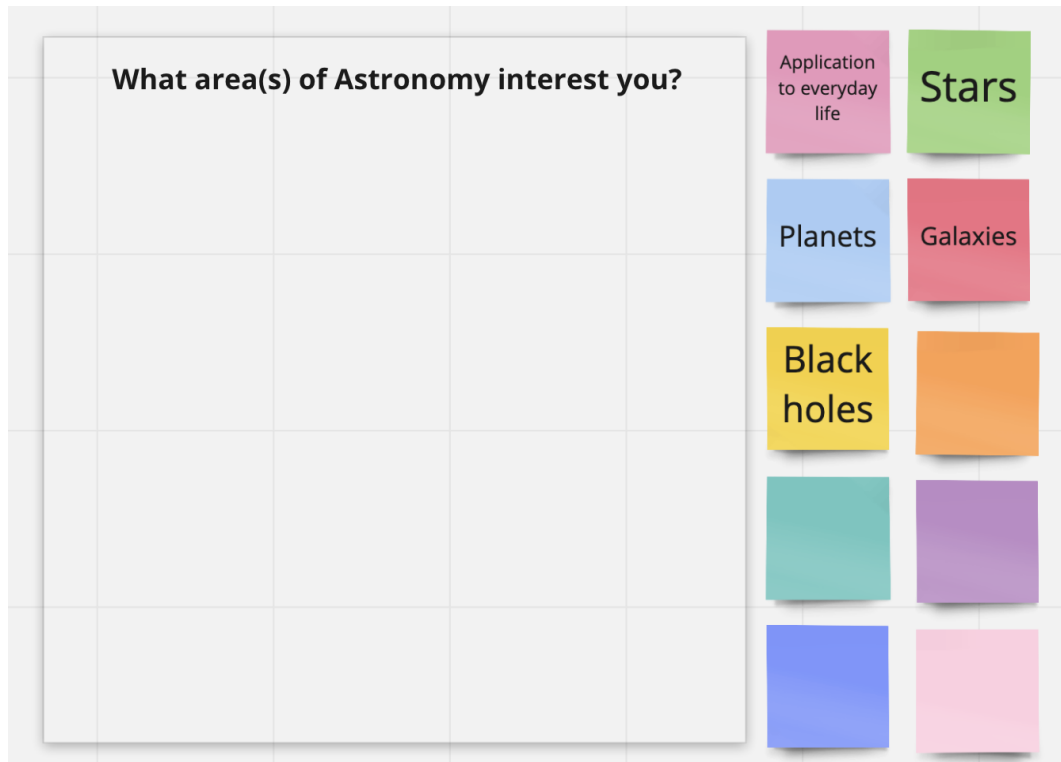
Figure 3.6: The initial setup for part of Task 1. Participants were asked to suggest answers to the two questions in the squares in bold, and write their suggestions on sticky notes placed in the boxes. We provided some suggestions to each question on sticky notes outside of the boxes in order to start the conversation. There were also blank sticky notes placed during the setup. This was to show that we are open to other suggestions and to make it easier for people who have not use Miro before to contribute. The task was duplicated as the discussions were taking place in breakout rooms, and two boards helped to avoid confusion between the groups.

up with a blank timeline of a 90 minute session and some suggestions for activities, shown in Fig. 3.7. These were taken from the flashcards constructed in Young, Perović (2016) and colour-coded according to the type of learning they correspond to. We wanted to leave the workshop design element as open as possible so that the workshop we created could meet the wants and needs of our participants as closely as possible and we did not want to influence them or drive them into a certain format. Additionally, giving a group agency over how they engage with material has been shown to increase the comfort of the group with material and the ease with which they learn it (Barton, Tan, 2010). This also supports the ethos of the co-creation method (Sanders, Stappers, 2008) in giving the group as much agency as

For task 3, we will be co-designing a workshop for the current A New Direction cohort. We will again be using sticky notes to populate the timeline below to design the workshop. We want to determine the duration of each part of the workshop, its content (i.e. what we are exploring) and the method used (how we are exploring the content) for each part of the workshop. Below the timeline are suggestions of activities which are colour coded to correspond with they type of learning they use.
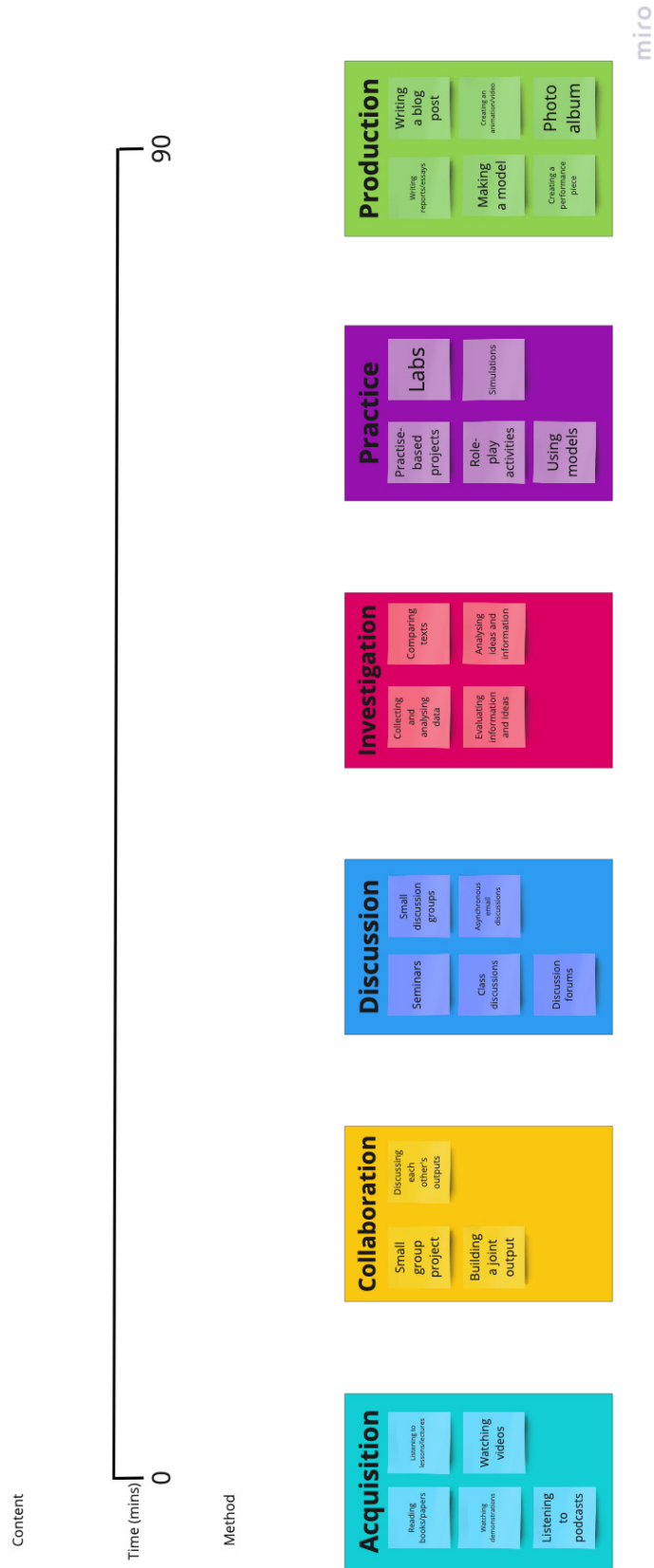
Figure 3.7: The initial setup for Task 3. The written description for the task is shown above the box. Inside the box is a blank timeline for a 90 minute session to develop skills and astronomy knowledge. We wanted the timeline to be as blank as possible to allow for the least biased and most creative session possible. Below the timeline, the six coloured boxes show the different types of learning. The virtual sticky notes inside these boxes suggest some activities related to that type of learning, taken from Young, Perović (2016). These were given as suggestions to the participants so they had ways of including different types of learning in the session. This would mean that there are parts of the session that everyone finds will work well for their development.

possible over the design of a workshop for people like them.

3.4.2 Results

In this section, we present the findings of the workshop. After the session was finished, we used the Miro boards as evidence of what was discussed in the session. An example of the results of part of Task 1 is shown in Fig. 3.8. We looked for themes across all three tasks in the co-creation session to identify what was important to our participants in a course. We also looked at the suggestions of ideas for activities presented in Task 3 and classified them into general themes to form a structure for a 90 minute pilot workshop.

3.4.2.1 Workshop feedback

During the final part of the co-creation session, we asked participants to complete a five minute questionnaire with a blend of formative questions reflecting on the process and summative questions to explore any attitude changes as a result of being part of the process. We wanted to make this a short questionnaire to encourage more people to take it, and so that it would fit into the timing of the co-creation session. Six of the eight participants of the co-creation session answered this questionnaire. **The questions asked can be found in Appendix A.2.**

We had generally very positive responses. In particular, people found that having assigned facilitators in the breakout rooms to be helpful and felt that using Miro allowed their views to be listened to even if they were not speaking on Zoom. The four people who answered the question *"Do you think you'd find taking the workshop we developed enjoyable and valuable? Why?"* agreed that, if their suggestions were listened to, the resulting workshop would be valuable and enjoyable.

We also gave participants room to tell us how the co-creation workshop could be improved if we were to run a similar event again. The two suggestions we received to improve the session were, firstly, to include a more physical activity or a "making element". Secondly, participants wanted to gain some astronomical knowledge from the session, particularly information about what the astronomers were doing in their research. We had not included a knowledge gain element in the
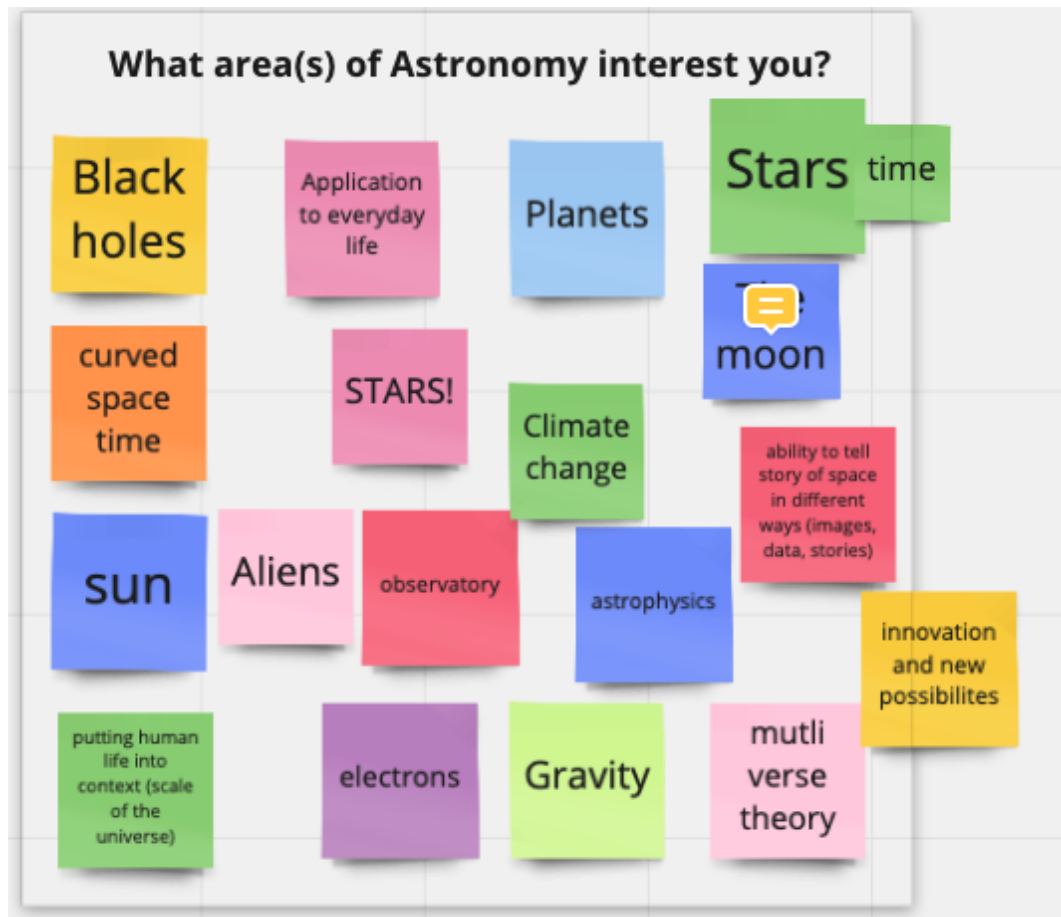
Figure 3.8: A screenshot of part of Task 1 filled by one of the breakout rooms. The coloured sticky notes show the participants' answers to the question *"What area(s) of astronomy interest you?"*. Colours were selected randomly by participants. Some of our suggestions were positioned outside of the box as shown in Fig. 3.6, and if the participants agreed with them they dragged them into the box. They also added their own sticky notes with original answers to the task. From all of the sticky notes across the tasks we extracted three themes which are discussed in Section 3.4.2.2

co-creation session in order to give the participants more time to share their views without bias from any of the session's designers. This survey showed that participants were disconnected from recent astronomical developments but were interested in astronomy and had a desire to learn more.

3.4.2.2 Themes

In total, we identified three themes spanning the responses to each of the tasks in the co-creation session. This was done by completing thematic analysis of the suggestions of the virtual sticky notes on the Miro board, using techniques presented in Braun, Clarke (2006). An example of one of the themes derived using this methodology and the evidence supporting it can be seen in Fig. 3.9. The themes are as follows:

Agency and respect – People wanted to be more involved and make more decisions on what they learn and how it is taught than traditional educational courses. This could help them develop the skill of leadership, which was brought up in the co-creation session. Participants wanted space to voice their views and ideas, whether this be through suggestions of a place to "test ideas", "dialogue", "peer feedback" and asked for a space for their questions to be answered. There was also a desire for participants to make connections with both other attendees and the facilitators, including through social media. Participants looked for respect, for example when the issue of timings was brought up. The participants wanted to make sure that the session would "stay on time" and feel "not rushed". Another example is the desire to want the workshop's "aims communicated" to them, and that they were concerned about keeping the knowledge it provides accessible to them. The theme of agency was also seen in the work of Dreyer et al. (2021) where it was found that participants felt more favourably about public engagement activities where they had more agency.

Stories (evidence for this is shown in Fig. 3.9) – The main way that people wanted to engage with science is looking at the stories of new developments and stories that can be told through science. This included suggestions to look at historical or ethical stories and case studies, as well as examples of what topics these
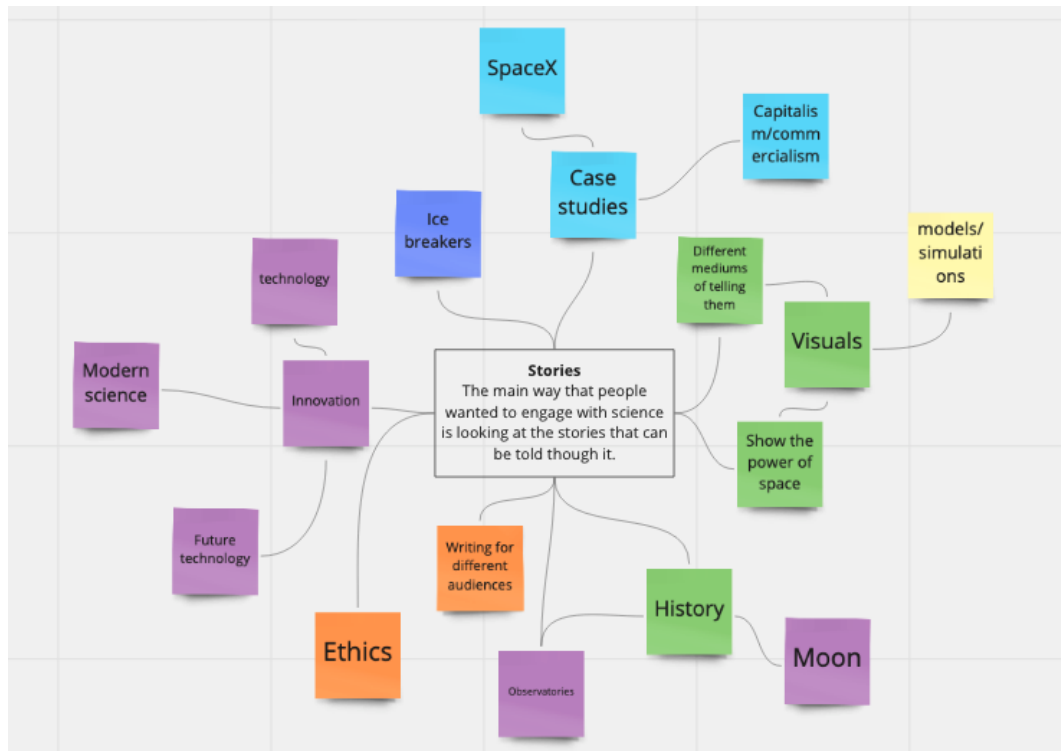
Figure 3.9: The theme of "Stories" extracted by thematic analysis (Braun, Clarke, 2006) from the notes made on the Miro board during the co-creation session. The central text box gives the theme title and a brief definition of the theme. The virtual sticky notes show suggestions from participants which support our theme and are coloured according to which task of the co-creation session they came from. Cream and orange are responses to the first question in Task 1, separated into technical and interpersonal skills, respectively. Purple shows responses from the second question of Task 1. Light blue virtual sticky notes are results of Task 2. Dark blue and green shows responses from Task 3, separated into general and astronomy ideas, respectively. Links have been made by the authors between different suggestions to show how they can relate to each other to build this theme.

stories could cover. There was also interest in "innovation" and new developments, both in astronomy and technology which could eventually be accessed by them. Specifically, "SpaceX" was given as a suggestion which could be told as a story. As expected for a group from the creative sector, they considered "different mediums of telling [stories]", including "writing for different audiences" and using "visuals" and "models/simulations", which are commonly used by astronomers. It was also suggested to start the stories early in the session, with the idea that they could be used as ice-breakers.

Development – As we emphasised that we would be designing a skills-based workshop, the qualities that participants wanted to gain and develop were mentioned frequently. The suggestions in this theme cover all six of the types of learning (Young, Perović, 2016). One of the concerns that was brought up was about "shyness", and how it might be hard for people to communicate amongst strangers or in the context of astronomy. However, linked to this was the suggestion to include activities to help people who are feeling shy begin to feel more comfortable and a skill that participants wanted to develop was confidence. Other interpersonal skills suggested include "collaboration", particularly in a multi-disciplinary context, project management and the ability to reflect. Some of the skills that participants wanted to learn are those that astronomers develop themselves during their careers, including handling data or working with spreadsheets, "programming" and critical thinking, the latter of which could be linked to "(dis)proving theories".

3.4.2.3   Proposed Workshop structure

During Task 3, participants gave suggestions on virtual sticky notes for tasks to include in a pilot workshop for skill-based learning using astronomy. Their suggestions could be grouped into the following themes for a structure of the workshop, as shown in Table 3.5. We had also included some suggestions from each of the learning types as discussed in Young, Perović (2016).

Introduction and icebreaker: Suggestions for the first part of the workshop covered introductory remarks. This included housekeeping for the platform(s) we decide to use and to "lay out structure/goals/aims" of the workshop. This section was to help get everyone on the same page. The next part of the session was to be dedicated to icebreakers and getting to know each other. One of the suggestions was to use an astronomy-themed icebreaker to help people get used to talking about astronomy topics.

Information gathering: Suggestions for the end of the first half of the workshop tended to be about information gathering, i.e. opportunities to learn about astronomy. These included suggestions for the format, including "small group discussions" and "watching videos" as well as potential topics, such as "dispelling

Section	Content	Method
Icebreaker and introduction	Housekeeping, lay out the session's goals, start conversations	Virtual discussions
Information gathering	Learning about astronomy: dispelling myths, case studies	Small group discussions, watching videos
Break	Comfort break, time to consider the next activity	Time to step away from the screen
Production	Developing skills	Programming, making a model/simulation, working with data, small group project
Reflection	Time to reflect on what was gained in the session	Peer feedback, creative writing, solidifying skills
Conclusions	Summarising the session, sharing resources to continue exploring what was done in the session	Evaluation questionnaire, sharing social media information

Table 3.5: A summary of the activity themes suggested by the participants of the co-creation workshop. The theme of each part of the workshop is listed in the "summary" column. The "content" refers to the knowledge or skills developed in each section. The "method" refers to what activities will be used in each section

myths" around astronomy, ethical issues and "commercialism/capitalism and astronomy".

Break: A 10 minute comfort break was suggested in the middle of the session. This would help with breaking up the session to help with the flow. One of the participants suggested that we include something to think about during this time which could help the transition to the next part of the workshop.

Production: After the return from the break, ideas given were more based on the format of the session rather than particular astronomy topics. Furthermore, the main theme for these ideas were focused on production, i.e. creating something. Some of these were based on computing and data, for example "making a visualisation", "simulations", "collecting and analysing data" and "learning how to do 1 task in a programming software". Other suggestions were based more on collaborative

ideas, such as "small group project", debates and "working in a group to decide something". Both of these types of activities can be linked with some of the skills discussed in earlier tasks, which was one of the aspects that the facilitators tried to encourage.

Reflections: A space for review and reflection was desired by our group. Some of the suggestions in this section included a question and answer element for the participants to find out more about specific areas of things that have interested them. There was a desire for some creativity in how the reflection was done, such as suggestion for a "creative writing task" and "writing out the skills you've learned/developed". Peer feedback was also suggested as a method of reflection. Summaries of what has been learned in the workshop were also suggested, and give smooth transitions to the finale of the session.

Conclusions: In this section, people were interested to give feedback and evaluation on the session, which could help improve the subsequent workshops. Also, they looked for next steps and ways to further their learning, demonstrated in the comment "what's next? what do we do with this information?" There was a desire to remain connected with people, both through sharing social media contact information and how to keep involved with A New Direction.

This workshop structure has been used to inform and develop the pilot workshop presented in Chapter 4.

3.5 Discussion

3.5.1 Analysis of Findings

The Research Methods in School Education (RISE) educational course ran a co-created pilot workshop (Sanchika Campbell, al. et, 2019) for sixth-form students relating to issues in public health. The authors found that taking a project-based approach, where groups of students investigated a topic relevant to their interests, worked well in engaging participants. They also found that interactive workshop activities, debates and discussions were very popular with their participants. This is similar to the findings from our co-creation workshop and supports our decision to

make our pilot workshop's main activities interactive.

One of the problems that arose with RISE was their students wanted clearer communication of the timetables and activities scheduled in their workshops. This is consistent with the theme of agency we have found in our work. Additionally, the pilot workshop ran by RISE was relatively short term. Whilst the authors measured increases in the confidence and knowledge of their students in academic circumstances at the time, they do not know if the benefits from this course are sustained long term. This concern is also true of our pilot workshop given its one-off nature.

We combined the data from the survey and the co-creation session to understand what our participants wanted from a course. As we were dealing with small numbers of participants our results will not necessarily be representative of the group as a whole, but we believe we still drew useful and valid conclusions from our data. The survey had twice the participants as the co-creation and covered a broader range topics, so gives us a view of the feelings of a larger group of people looking for employment in the cultural sector. We also gained quantitative information from the survey. On the other hand, the co-creation session allowed for much deeper discussion of certain areas and allowed participants to discuss ideas and explore them in greater depth.

Task 1 of the co-creation session included answering the question *"What skills would you liked to have learned when you were working with A New Direction?"* Before the session, we included some suggestions from the survey question *"Which skills or knowledge would you be interested in gaining from a course?"* Of the five suggestions we put on the Miro board, only "collaboration" and "programming" were used between both breakout rooms during this discussion. For comparison, in the same task one breakout room used two of our suggestions for astronomical topics and the other group used all five suggestions. This is interesting because some of the suggestions that were suggested in the survey were reasonably popular amongst those who took it, but then were not brought up at all in the co-creation session. This could be because the co-creation participants also answered the survey so may feel that they have already expressed their opinions on those topics.

An important area discussed in the survey was the idea of barriers which could prevent people from taking part in our sessions. Aside from the occasional mention of "shyness" this topic was not discussed at all in the co-creation session. On the other hand, when we specifically asked about barriers in the questionnaire, we gathered 14 responses stating that accessibility requirements and required knowledge of maths, science or astronomy may prevent people attending a workshop. It is important to remove as many of these barriers as possible to allow everyone to feel able to come to this session.

During the co-creation session and in the survey, we invited participants to express issues that might make them feel uncomfortable or unwelcome in our sessions. Participants gave us their views trusting that we will make an effort to remove these barriers. It is important that we respect these views to show that we are listening to our participants (Dreyer et al., 2021). Not doing so would be an abuse of their trust and is likely to put them off interacting with science and scientists further.

On the other hand, a positive experience could lead to them being more involved in science after the course has ended. Potential ways to do this include making science more welcoming and less elitist, showing mutual respect and addressing any perceived power imbalances between participants and leaders of events. An example of where this was not done is given in Dawson (2019), where one of the participants of the research conducted earned a biology masters degree in Sierra Leone, but was refused employment in the science sector, or any validation from UK scientists as his degree was achieved abroad. This put him off interacting with scientific environments for years. Additionally, titles (e.g. Dr, Prof) should not be used as they increase the perceived distance between facilitators and participants, and give academics a higher status, reproducing power imbalances (Humm, Schrögel, 2020).

The results presented in Archer et al. (2021) show that, in school students, one-off events have limited effects on raising students' aspirations or supporting science capital. Instead, it was demonstrated that positive effects are produced mostly from having exposure to science events and scientists over time. We expect that similar effects will be produced from our work here, though we are working with adults. We

doubt that the indicated science capital of the people who came to the co-creation session will change long-term. However, the positive experience participants reported in the co-creation could support participants' science capital even though they showed no measurable change directly after the session. Similarly, we expect the effect of the stand-alone pilot workshop we are designing to have a minimal effect on participants' science capital in the long term. This is one of the reasons that we believe a longer-term course would be beneficial. In addition, it means that we could work on multiple skills over time and develop some of them in detail. We plan to use the pilot workshop as a trial session for the course. We will be looking for feedback from participants after the pilot session which we can then incorporate into a longer course.

An unexpected outcome from the co-creation session and the three responses to the final thoughts survey was that the participants wanted to have gained something from the co-creation session. They felt that they mostly gave knowledge and did not feel they received any in return. Participant knowledge gain was not a main aim of the co-creation session and we did not have time to include it in our co-creation session as it was designed. In particular, the group were interested in the work of the two astronomers who were facilitating the session. Therefore, if we were running the co-creation session again it would be beneficial to our participants if an opportunity for them to gain knowledge of astronomy was planned into the session, perhaps by increasing its length to allow for time to explore this properly. This would ensure the workshop would be mutually beneficial.

3.5.2   Pilot Workshop Development

The next step would be to design and deliver a pilot workshop based on the findings presented in this work. Details of the development of this pilot workshop can be found in Chapter 4.

We intend to use the structure given in Task 3 of our co-creation workshop and detailed in Section 3.4.2.3, i.e. introduction, ice-breaker, knowledge gain, break, production, review and finale as seen in Table 3.5. The resource should use an astronomy topic of interest to the participants throughout the workshop and under-

pinning the skills taught. For example, if a discussion or debate is held then the topic of the activity would be related to astronomy; if we decide to use a programming task, then the data or model will be astrophysical in nature. We should use suggestions of topics from the participants and themes we have deduced from the workshop.

In addition to this structure, there should be some pre-activities for the pilot workshop. Much of this was discussed in Task 2 of the co-creation session. It includes communicating the code of conduct and structure of the workshop with the participants before the session. In addition, if we will be including brief biographies again, as discussed in Section 3.4.1, these should be completed before the session begins. This will need to be taken into account during the planning of the workshop, and considered if the participants are to be reimbursed for their time.

The combination of arts subjects with science has been shown to better enthuse underrepresented groups with science (Pompea, Russo, 2020). Therefore incorporating arts-based methods of engagement, **such as creative writing, role-play or drawing,** with astronomy would both align better with the interests of the intended participants and provide opportunities for engagement practitioners to learn new appropriate ways of exploring astronomy with different groups. Archer et al. (2021) showed that the impacts of standalone sessions can be improved by finding ways to link the subject matter to the experiences of participants. Focusing our workshop on developing relevant skills will allow us to make this workshop more memorable and impactful. In addition, we should find an area of astrophysics that is relatable for people so the information and skills will stay with the participants for longer. This is another reason why running a course or series of workshops would show lasting benefits for the participants and support their science capital.

Chapter 4

Pilot Workshop Design

4.1 Introduction

In this chapter, we use the findings from the survey and co-creation session discussed in Chapter 3 to develop a pilot workshop which can be run to develop career-relevant skills chosen by jobseekers. We discuss the insights on effective workshop design we have found, both from the work with A New Direction alumni presented in Chapter 3 (Section 4.3) and from the literature (Section 4.2). We then present the content and purpose of each section of the workshop including what skills it will develop and what influenced its creation in Section 4.4. Finally, in Section 4.5 we evaluate the course against the YESTEM Equity Compass (Godec et al., 2022), the ABC Course design method (Young, Perović, 2016) and Rosenshine's principles of instruction (Rosenshine, Stevens, 1986). **This work was completed by Choong Ling Liew-Cain**

4.2 Summary of insights from the literature

Instead of using formal examinations to assess the knowledge gain of students, there are more creative, enjoyable and equitable ways which we can assess participants' gains from the course. Schumm et al. (2022) found that asking undergraduate physics students to construct a problem based on the course material then find solutions to the problems they created showed students' grades correlated with their performance in traditional examinations. However, the results seem more equitable than in written exams; there was less of a difference between the average grades

of women, under-represented groups in physics, first generation further education students, and their respective counterparts. In a project-based learning situation, the meta study conducted by Guo et al. (2020) studied 76 reports of courses using this technique. These studies discuss various ways of assessing what participants have gained from courses, including using self-assessment questionnaires and examining participants' creations from these projects. These findings show that there are methods which can assess progress in a course that are equitable and do not require formal examination, which could be useful for our course.

Diversity and equity are also important considerations of course participants as well as astronomers and astronomy instructors. A study of 50 years' of data from the International Astronomical Union's youth camps (Archipley et al., 2021) has shown that the gender ratio of students at these camps is correlated with the genders of camp leaders. The youth camps had less success with promoting ethnic diversity, but state that the observed lack of diversity is affected by factors such as the lack of budget to pay for travel outside of Europe. From this, we believe that if our course is run by a group of people who represent the diversity of our participants then they will be more likely to engage with the course and have a positive image of astronomy.

4.3 Insights from the results of the co-creation session

The structure of our pilot workshop is taken from analysis of the suggested activities in Task 3 of our co-creation session (see Section 3.4.2.3). These activities were written on virtual sticky notes by our eight participants and placed on a 90-minute timeline. We provided a blank timeline on Miro[1] and participants placed the activity suggestion where they felt it fit best. Analysis of the themes of these suggestions meant we could split the workshop into sections: introduction, icebreaker, information gathering, break, production, review and conclusion. These sections are shown on the timeline in Fig. 4.1. We decided the timings of each of the parts ourselves

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[1] `https://miro.com/`

rather than use the fraction of the workshop timeline allocated to such activities. This is because there was not always a clear transition between suggestion types on the timeline due to space constraints, and based on our experience with running the co-creation session and other workshops, we believed some sections will need more or less time than the represented area on the timeline.

The contents of the workshop are also influenced by the findings of the co-creation workshop. Using thematic analysis (Braun, Clarke, 2006) we constructed three themes from the suggestions of the participants. More detailed analysis and results of our findings is presented in Section 3.4.2.2. One of the themes – Stories – showed that our participants **relate** best to astronomy through stories. Therefore, if we are able to incorporate case studies into our work that would be most likely to help them to gain something from the session. Participants were also interested **in** how astronomy can influence technology and their lives. The results of our survey demonstrate that this would be a good topic to cover too, as five out of 16 of the participants said they were not sure of any ways in which astronomy affected their lives, and a further three responses mentioned astrological effects without mentioning anything relating to astronomy.

With regards to the skill content of the workshop, both the survey and one of the themes from the co-creation session provide subjects which the participants wish to develop. The most popular skill from the quantitative data collected in our survey was programming, with 75% of responses interested in gaining related skills. One of the intrapersonal skills that the participants were interested in developing is problem solving. **The skills of programming and problem solving can be combined together by giving participants a coding task which would develop both of these skills. Therefore, we decided to include a coding task as the production section of the workshop.**

The interpersonal skill that had the same level of interest as problem solving, i.e. 50% of participants, is collaboration. In the co-creation session, this was also mentioned and in particular there was interest in collaborating with people of other interests or across disciplines. Another skill that could be taught well alongside col-
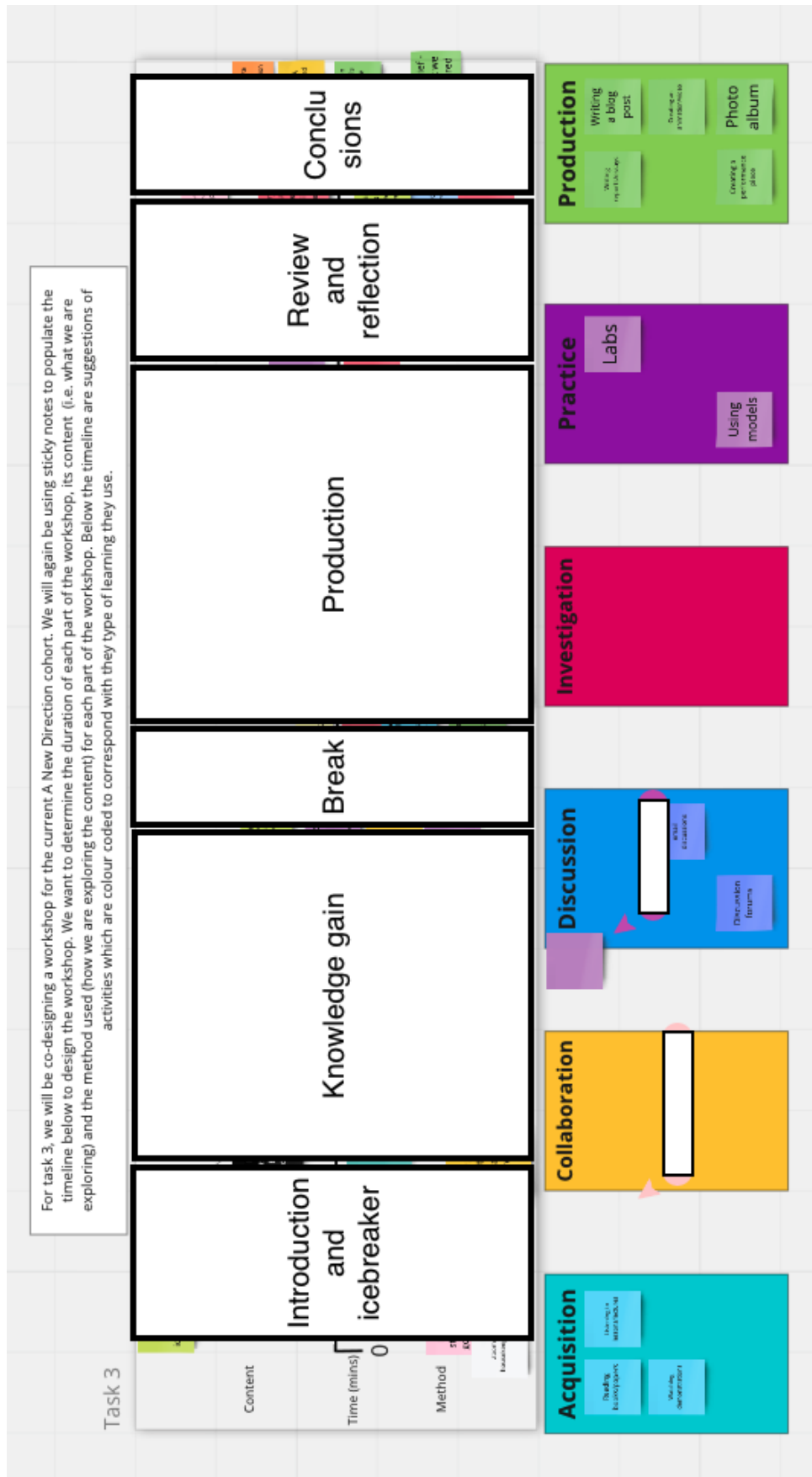
Figure 4.1: A screenshot of the Miro board for Task 3 of our co-creation session. The sticky notes with suggestions for activities in the 90 minute workshop were placed on the board. These have been grouped into themes for different types of activities, as shown in the labelled boxes over the timeline. Suggested activities, taken from Young, Perović (2016), were colour coded and placed in boxes with their corresponding learning type below the board. The virtual sticky notes remaining in the boxes were not used in the sessions. The names of participants, which were attached to their cursors, have been hidden by white boxes for privacy reasons.

laboration would be confidence. Creating an environment where people could work together in a non-judgemental and supportive environment can help to build their confidence, especially since one of the barriers to this session commonly named in the survey was lack of confidence or intimidation in settings where science and astronomy are discussed (see Section 3.3.1). **To develop these skills, we decided to have the information gathering and review sections feature large discussion elements to help build confidence and develop collaboration skills.**

The final theme that we found in the co-creation session is that of agency and respect. The participants wanted time to share their opinions with everyone and have them listened to. This means that having time for discussions will be very important to our participants. Additionally, one of the suggestions in the co-creation session was to have time for "peer feedback". This suggestion fits with this theme and is a valuable way that participants can interact with each other and develop in this session.

4.4 Workshop Design

For our pilot session, we constructed the following objectives for our participants:

- To have a positive experience of astronomy, and to meet other people who are interested in astronomy.

- To understand how astronomy can be relevant to everyday life.

- To understand that the laws of physics work the same way on different scales.

- To have a go at programming a planet moving around a star in Scratch.

If these aims are met, then the participants will leave with an improved attitude towards astronomy, feel more confident in understanding how programming works, understand how connected their lives are to astronomy and notice its impact.

4.4.1 Advertising

When the pilot session is advertised, there is certain information that will need to be made available to potential participants. Contact details for at least one of the

session organisers should be provided in case potential participants have questions about the session.

The workshop will take place online to remove the associated costs of travelling to a venue and to make the course more widely accessible than an in-person workshop. We will need to make sure that everyone has access to the platforms that we will be using. These three platforms (Zoom[2], Miro[3] and Scratch[4]) are free to use, which removes a potential accessibility barrier to participants. Miro and Scratch also don't require any installation and can be used in a browser. This will promote accessibility of our workshop and advance notice of the software we will be using will help participants feel confident that they will be able to interact fully with the workshop.

Following the theme of agency we found in the co-creation session, we should make it clear in the session advertisement what skills will be taught in the workshop. The choice of skills also links to the co-creation session's theme of development. Since one of the aims of the workshop is to equip participants with career-relevant skills, we need to make sure they are aware of what they can gain from attending the workshop and decide if the workshop will benefit their careers. This is particularly important as people who are looking for employment in the arts and cultural sectors may feel distant from astronomy and be unsure of a how an astronomy-based workshop could benefit them.

One of the main barriers identified in the answers to the survey we ran (see Section 3.3.1) was academic intimidation. This means that our participants may feel detached from and anxious around astronomy. Therefore, we need to emphasise that no prior knowledge is needed in any subject (including astronomy, science or maths) for participants to be welcome in the workshop. Instead, we should focus on the attributes of the participants that will be useful in the session, which are curiosity, desire to learn new things and willingness to share their experiences of the world. The aim of this is to make the participants feel welcome in this workshop

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[2]https://zoom.us/
[3]https://miro.com/
[4]https://scratch.mit.edu/

even if they have been out of contact with astronomy.

4.4.2 Pre-session

Before the session begins, we will send out some information to the participants. This includes a timetable for the session, so that participants know what to expect in the session and can make sure that they have access to the software we will be using. Also, we will send them a copy of our code of conduct, so the participants know what we expect from them, both in terms of how we will be using the software (e.g. keeping muted on Zoom unless they are talking, and the use of cameras is optional but encouraged) and the behaviour we expect them to display towards the other people in the course.

We want to send participants a short, anonymous questionnaire before the session. This will help us to assess the level of astronomy knowledge amongst the participants. We can use this information to split participants into breakout rooms to make sure that the groups are as balanced as possible to allow for productive discussions in all groups. We will also have questions to estimate the science capital (Archer et al., 2015) and attitudes to astronomy and science of the participants. We will compare these results similar questions in the post-survey session (Section 4.4.4) to evaluate the outcomes of our workshop.

4.4.3 Workshop format and content

The workshop will last 90 minutes and will be a one-off event. We decided on the time as 90 minutes gives enough time for multiple activities using varied types of learning to occur in enough depth to allow for some skill development. It is also a short enough time, especially with a break during the workshop, that it should not be problematic to most people with accessibility requirements. The workshop is a standalone so that we could use evaluation collected from this workshop to improve subsequent workshops. The following sections will describe the activities and timings for the course on the day.

4.4.3.1   Introduction (5 mins)

The first part of the workshop is to be used for housekeeping. This includes going over the timetable for the day and details of how we will be using the video and note-taking platforms in the session. This is so that everyone knows what is going to happen and feels confident in how they can contribute and develop within the session.

4.4.3.2   Icebreaker (15 mins)

The icebreaker is to let people introduce themselves, including their names, what they do and their interests. In order to get people to start to think about astronomy, we will also be asking them an astronomy based question as they introduce themselves:

> It is several hundred years into the future and a team of astronauts have arrived at an exoplanet. An exoplanet is a planet that is orbiting another star. What is one feature that you would like this planet to have? It could be geographical, climate, life-related or anything else you can think of.

This promotes creative thinking, uses the imagination in a way that the participants might not be used to applying to astronomy, following the theme we found in the co-creation session of stories. This will appeal to our participants, who are looking for careers in the arts and cultural industries. The icebreaker gives everyone a chance to meet each other and feel happy talking to each other. From the themes found in our co-creation workshop, the icebreaker contributes to the theme of agency and respect by giving participants time to make connections with the other people in the workshop and contributes to the development theme by helping to combat shyness.

4.4.3.3   Information Gathering (15 mins)

We intend the information gathering section to be where participants can learn new things about astronomy. We have chosen the topic of gravitational orbits for the pilot session. This topic was selected as the underlying physics is the same across

many scales of astronomy, from the Earth's artificial satellites to the motion of stars within galaxies. Within the scope of this topic, there is also space to discuss many of the areas of astronomy that were of interest to the participants of our co-creation session, including the impact of astronomy on their lives, "stars", "planets" and "the Moon".

To begin the section, we want to start with a 10 minute discussion in breakout rooms. The topic of discussion will be *What would we want to send into space? Why is it useful to send things into space?* This discussion will focus on artificial satellites that humanity have sent into orbit around Earth. Many of these have a direct impact on the participants' lives, including global positioning system (GPS), weather observation and forecasting, internet and communication. We believe this will help the participants see how astronomy can have an impact on their lives. We want to focus on the relevance on astronomy in daily life because in our survey very few of the participants were able to name a tangible way astronomy affects them directly. In addition to the ways in which satellites impact daily life, there are other astronomy-related topics that can be discussed. This includes the zero-gravity environment in the International Space Station, human spaceflight and astronomy research which have other implications on the lives of humanity.

The use of breakout rooms means that, since we will be working in smaller groups, each person will have more of a chance to share their ideas or voice their opinions. We would also have a facilitator in each of the breakout rooms to guide discussions if required, to make sure that information shared is as accurate as possible and to suggest ideas if participants are unsure of what to talk about.

The final five minutes of this section will be creating a shared experience. We intend to watch a video showing that gravity makes the planets orbit the Sun and the Sun orbit the centre of the Milky Way in a similar way to how satellites orbit the Earth. This visual explanation of how bodies move through space should be inspiring to the participants, and can get them to think about the next task. It also "show[s] the power of space" which was a suggestion we received in the co-creation session.

A brief description of the production activity (about two minutes) will be given at the end of the section. This is to give participants a chance to consider their approach to the task whilst they take their break.

This section continues to build on the theme of stories by discussing technology, innovation and modern science. There are opportunities for participants to discuss case studies, such as organisations that have sent objects into space. The way we have framed this section makes it interactive, gives participants space to test their ideas and have a dialogue with the other people in their breakout room. These three aspects are suggestions under the theme of agency and respect.

4.4.3.4   Break (10 mins)

The break gives everyone time to step away for their comfort and helps to make the course more accessible to people who might struggle to be seated or use a computer for a long period of time. It also gives the participants some time to consider what they might want to do with the next part of the workshop.

4.4.3.5   Production (25 mins)

The production component of the workshop allows the participants to make something tangible and develop skills as they do so. In both the survey and the co-creation session, one of the most popular desired skills is the ability to program. Due to the limited time and one-off nature of the workshop, we decided to use Scratch to teach the basics of programming. This simplifies the coding process as, instead of writing syntax themselves, Scratch features coloured blocks which can be pieced together to form an algorithm. Additionally, Scratch allows the use of "sprites" or images that can be programmed using their codes, creating a visual display of what their code does. This animated element will appeal to the creative jobseekers we are working with us, demonstrated by the suggestion of "visuals" to make a good workshop in the co-creation workshop we ran.

Using Scratch, we want participants to make a "planet" sprite move around a "star" or "sun" sprite in a repeating motion, much like the motion of the Earth around the sun. We do not expect participants to use equations of motion, numerical integrators or more complicated mathematical or computational ideas in this

section. Making a simple looped set of instructions to make the planet move will be sufficient for participants to be able to gain an idea of how coding works, which is the aim for this section of the workshop.

This section focuses on the the critical thinking, putting ideas into practice and programming aspects of the development theme discovered during the co-creation session. Scratch is visual, both when constructing code and when viewing the coded model, which were suggestions from the theme of stories.

We made a demonstration of a planet's orbit around a star in Scratch to demonstrate how the software participants are using can be used for science. We modelled the planet's motion using a Leapfrog integrator using Newton's law of gravitation. The code computed the motion of the planet in two dimensions. The *x* and *y* components of initial position, $\vec{x_0}$ and velocity, $\vec{v_0}$ could be input to the code as free variables.

$$\vec{v_{\frac{1}{2}}} = \vec{v_0} + \vec{a_0}\frac{\Delta t}{2}$$

$$\vec{a_n} = \frac{-GMm}{r_n^2}\frac{\vec{x_n}}{r_n}$$

$$\vec{x_n} = \vec{x_{n-1}} + \vec{v_{n-\frac{1}{2}}}\Delta t$$

$$\vec{v_{n+\frac{1}{2}}} = \vec{v_{n-\frac{1}{2}}} + \vec{a_n}\Delta t$$

where Δt is the time increment, n in the number of increments passed, $r_n = |\vec{x_n}|$, M and m are the masses of the star and planet, respectively, and G is the gravitational constant. We set $GMm = r_0^2$ to keep the planet moving within the animation area on Scratch. The demonstration can be viewed at `https://scratch.mit.edu/projects/598720620` and a screenshot is shown in Fig. 4.2. We are aware that understanding and programming these equations in Scratch is likely beyond what our participants could create in the 25 minutes that we have allotted to this section.

4.4.3.6   Review (15 mins)

The first five minutes of this section should be used for the participants to reflect on what they have gained from the session, what was beneficial and what more they would have liked to see. We will also remind them of the session's objectives so
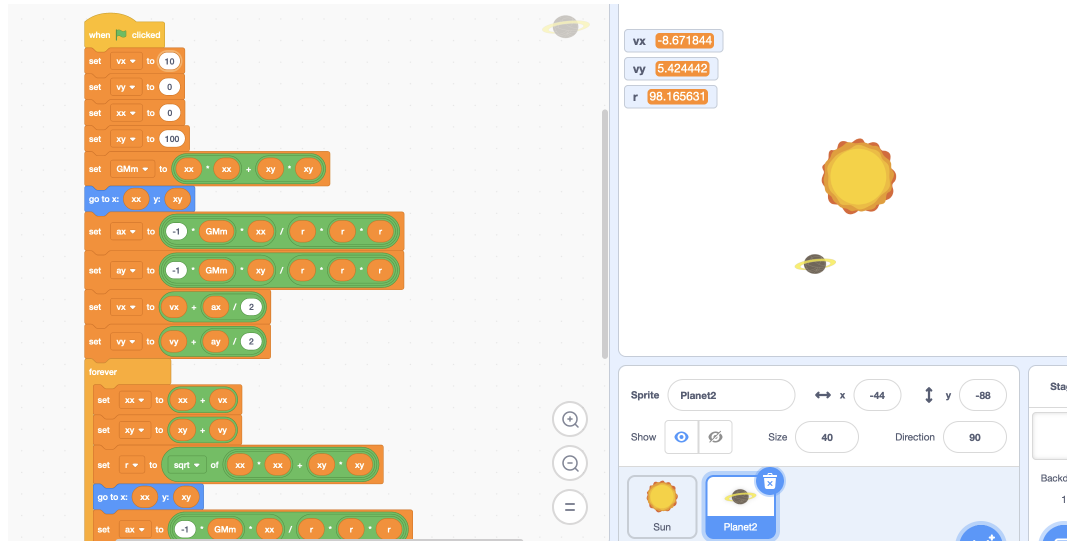
Figure 4.2: A screenshot of the Leapfrog orbit code and animation written using Scratch which will be used as an example in the pilot workshop. The planet moves around the sun (which is stationary at (0,0)) according to the equations detailed in Section 4.4.3.5. Components for initial position and velocity of the planet can changed by inputting values for *xx*, *xy*, *vx* and *vy*, respectively. We have set $GMm = r_0^2$, the initial distance from the Sun, so the orbit scales to fit within the animation area. The simulation can be viewed at `https://scratch.mit.edu/projects/598720620/`.

they can assess if they have met these targets. After this, we will split them into breakout rooms where they can discuss their reflections. The ability to discuss what they have gained will hopefully bring out more points that had not occurred to some people and help clarify other points. Furthermore, it allows the participants time for peer feedback and to form connections with each other which were suggestions from the co-creation session about what makes a good workshop.

We will also ask participants to make some notes of their reflections on a Google Docs or Miro board, which we can use to evaluate how well they engaged with the session and its effects on them. This will include what skills and astronomy knowledge they developed, how accessible they found the course, what else they would like to learn and where improvements can be made. We can use this evaluation as feedback on how to develop future workshops or a course.

4.4.3.7   Conclusion (5 mins)

In the final five minutes, we will be concluding the workshop. This will include emphasising some take-home points from the session and introducing ways for people to continue to develop the skills used in the session or their interest in astronomy. For example, this could be by providing a selection of materials for further information about topics we covered or other tools which can be used to develop and practice skills participants gained in this workshop. We would also like to provide a feedback questionnaire for the participants to fill out in this time which, in combination with the notes from their reflections, can be used to evaluate the effectiveness and appropriateness of this course. We will ask questions on similar topics to those covered in the reflection section and the pre-session survey. The latter will allow us to measure the outcomes of the workshop.

4.4.4   Informing Further Courses

The motivation for running this pilot workshop is to gather feedback from participants which can be used to design a longer running course with the purpose of teaching career-relevant skills using astronomy as an inspiring medium. Therefore, we will be looking to gather opinions from the people who attended the pilot workshop.

We have set out four aims for the session in its design (see Sec. 4.4). We want to know if participants think that these aims align with their expectations for this workshop, if they were appropriate for the 90-minute session and if they felt that they met these aims. It will be useful to know if having these aims for the session helped to focus their efforts during the activities. Collecting aims that participants have would be useful as these could give inspiration for the subsequent course.

Whilst we have constructed this workshop to teach certain skills, it would be valuable to hear from the participants what they feel that they have gained. This will indicate the effectiveness of the methods we used to teach the skills, and therefore can help us to identify good methods for use again. It would be interesting to see if the participants feel that they have developed skills that we had not been targeting in the workshop, and if there are specific skills they would also like to develop during

a course. This could inform the design of the longer term course and it gives further agency to the participants over what they develop.

As this course uses astronomy as motivational vehicle, we want to measure any changes in participants' opinions towards the subject. This will be to test our theory, which we have concluded from both our previous work and other literature (e.g. DeWitt, Bultitude, 2020; Trotter et al., 2019) that astronomy can be an inspiring subject and attract people who don't see themselves as scientists. We want to see if the participants feel that the astronomy element makes the workshop more interesting or engaging. Additionally, it would be interesting to see if this one-off session has any effect on the estimated science capital of participants, even though we don't expect to see any changes from this one-off workshop (Archer et al., 2021).

Finally, we should investigate how accessible the course was for the participants. This can motivate many changes to the course we design. This could include how we advertise the course, as we could be putting people off attending, the level of the content of the course (i.e. if the participants find it to be too simple or too challenging) and if the platforms we used were suitable for the attendees to express themselves or ask us questions. We want all participants to be able to take part and have an equal voice and to ensure the software we use enables this. We want our subsequent course to be as welcoming and useful as possible to the participants so accessibility is a key concern for us.

4.5 Evaluation and analysis

In this section we analyse our plan for the pilot workshop against a selection of published best practise literature to see what has the potential to work well and what could be improved. The following sections contain evaluation of our course against the work named in the section title.

4.5.1 YESTEM Equity Compass

We have used the Youth Equity in Science, Technology, Engineering and Mathematics (YESTEM) Equity Compass (Godec et al., 2022) to evaluate the effectiveness of our pilot workshop. Originally, the Equity Compass was developed to help im-

prove informal science education for children and young people but has previously been applied to wider schemes, including work with adults, which is relevant to our workshop. The co-creation approach we took in designing this workshop has been beneficial in ensuring that we allow the participants to have agency in the workshop and helps them take ownership of the role of astronomy in their lives. In particular, this will be emphasised during the discussion element of the workshop, where the voices of the participants can be expressed and their experiences can be validated with respect to astronomy. This shows that our workshop does well in the "working with and valuing minoritised communities" area of the Equity Compass. By having places where the opinions and concerns about astronomy could be expressed in the co-creation session and survey for the design of the pilot workshop, we are able to recognise how inequity has affected participants' experiences of science. These views were taken into account when the pilot workshop was designed, which helps us to embed equity into our workshop. For the "challenging the status quo" portion of the equity compass, the co-creation element of the workshop has helped with the areas of "prioritising minoritised communities" and "redistributing resources".

Our workshop fares less well with the "transforming power relations" segment. We do not formally cover the accessibility of science and the effects the stereotypical scientist being elitist, white and male even though we know from our survey that representation and diversity is one of the factors that can turn people away from the workshop. Whilst the co-creation session is likely helpful for the ownership of the workshop being associated more with the participants, we are unsure about how that will affect their relationship with science. This is also a concern because, whilst we have made efforts to follow the suggestions for the pilot workshop made in the co-creation session, ultimately this workshop was designed by scientists who are currently the dominant voices in astronomy. Furthermore, this workshop does not do very well in the "extending equity" portion of the compass. By its nature as a standalone workshop, it will have little impact in the long term. However, if the feedback from this is used to develop a course, that will produce a longer term effect as it will be taking place over a number of weeks or months.

Similarly, the workshop is oriented to cater for the participants and not their wider community. One way we could have addressed this is to have conversations about how the participants might best share what they have gained from the workshop with friends and family. Alternatively, if we are able to increase the confidence of attendees around science and astronomy, they might feel able to visit places such as science centres or museums with others, which would then have a more widespread effect in the community.

4.5.2 Rapid and creative course design

We calculated how much time was devoted to each method of learning (acquisition, collaboration, discussion, investigation, practise and production) from *Rapid and creative course design* (Young, Perović, 2016). We found that our workshop focuses mostly on the "production" and "discussion" elements from the programming and discussion sections of the workshop, respectively. However, other skills are included in these sections. The brief video that we plan to watch at the end of the discussion section is best described as an "acquisition" activity. During the discussion, we are hoping that the participants will be able to build off each others' ideas, which is an important aspect of "collaboration". Similarly, the chance for peer feedback also builds collaborative skills. Whilst the programming activity is focused on "production", there are also elements of "investigation" and "practise" present. This is because the participants will be investigating how programming works and the effects of different lines of code, and can apply some of the knowledge they gained earlier in the workshop. Though there is an imbalance between learning types, as seen in Fig. 4.3, if this is made into a longer-term course then different sessions could give more focus to each learning type to make the overall course balanced. By incorporating all of the types of learning into the workshop, we hope that everyone will be able to engage with different parts of it.

4.5.3 Rosenshine's principles of instruction

Rosenshine's principles of instruction (Rosenshine, Stevens, 1986) present strategies to improve the quality of teaching in schools. The results are based on obser-
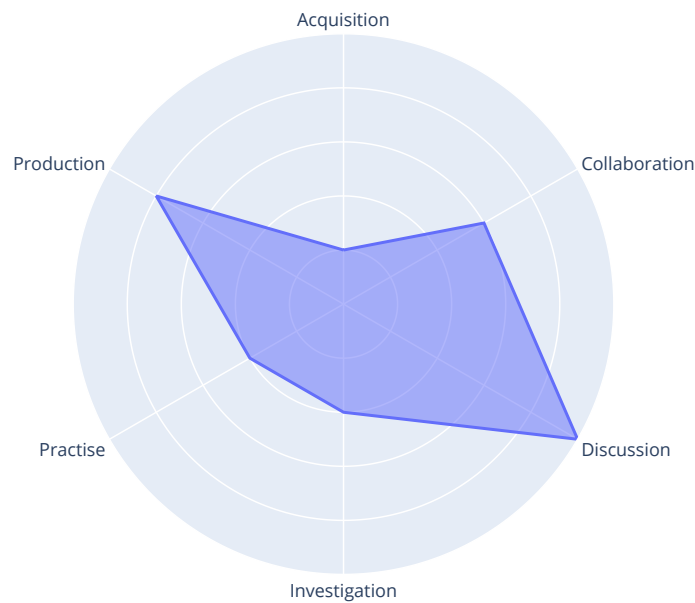
Figure 4.3: A spider diagram, similar to those in Young, Perović (2016) showing the relative frequency of learning types used in our pilot workshop. We focus on the discussion and production in this workshop during our discussion and peer feedback, and programming sections, respectively. The other learning types are used throughout the workshop but there is less focus on them.

vations of teachers in their classrooms. It was found that teachers who followed or included these principles in their lessons, when compared to teachers who did not, generally kept the attention of their students longer, were interrupted less, were able to provide more direct feedback to students and created a warmer, more supportive learning environment.

Rosenshine (2012) summarises the principles of instruction into points which we have compared our pilot workshop against. Some of these points are not relevant to our workshop due to its one-off nature, but would be useful for a longer course. This includes reviewing material learned on a weekly or monthly basis, ensuring students achieve a high success rate when answering questions, and beginning lessons with a review of the content of the previous lesson. We start the information gathering section of the workshop with by relating the astronomical topic of orbits to participants' lives. Whilst this is not a direct review of material

which has been previously learned, it does help to make connections between participants' experiences and astronomy which is the aim of the author's original point.

Of the points presented, there are some that our workshop does not address well, such as modelling how to solve problems and guiding student practice. It would be more beneficial in our workshop to show participants a blank Scratch workspace and model how to fit code blocks together to make a program. Our current plan to initially show a mathematical model of a planet in orbit does not provide much guidance and may be overwhelming or intimidating if participants have not used Scratch or a programming language before. There is limited time for independent practice during our session. Part of the the independent practice principle is that the teacher should be able to interact quickly with individual students. However, in our virtual session it will be harder for the facilitators to quickly interact with participants as they will not easily be able to see their work. The participants may also not be willing or able to share their screen which would hamper quick and effective feedback from the facilitators.

On the other hand, there are principles presented in Rosenshine (2012) which our course follows. For example, we present material slowly and in small steps. We do this by initially making the course's theme of orbits directly relevant to participants' lives, then slowly increasing the level of abstraction by applying the theme to much larger scales of planets and stars. Finally, we use the topic in a programming and animation context. These small steps make it easier for our participants to understand the larger topic as they are not presented with a large volume of information at once. We also use the principle of helping students practice and correct what they have learned. One of the suggested methods for this is for student discussion, which will be included in the information gathering section of the workshop. This allows for students to share their views and learn from each other, which reinforces the information they gather. We will also have facilitators present in the breakout room who can "correct what they have learned" and "check student understanding". This is important because the author emphasised that it takes much longer to correct learned errors than to teach the concept properly first time. Our workshop

uses scaffolding, which is the concept of including supports for students while they learn a subject and taking them away as they gain confidence. We do this by using Scratch to teach programming. Scratch was beneficial as the code blocks allow users to construct algorithms without needing to write the full syntax themselves. This scaffolding could be removed in later sessions of a course when participants feel comfortable writing programs in a text editor without the structure of the code blocks.

4.6 Testing the pilot workshop

To test the workshop described in Sec 4.4, we ran a modified version of it with a cohort of six sixth form students from Wetherby Senior School. All of these students were taking A Level maths and further maths, but their other subject choices varied. Wetherby Senior School is a selective, fee-paying boys' school. Testing the workshop in a school environment allows us to have a teacher present to allow for additional evaluation. As the observing teacher is familiar with the participants of this test workshop, they will be able to give us information we would be otherwise unable to obtain, such as whether participants were more engaged in our workshop than they would be in a normal learning environment.

This test workshop has been granted ethical approval by the UCL Research Ethics Committee; Project ID: 24635.001; Title: *Learning with Astronomy: Inspiring, Skill-Based Learning*. Choong Ling Liew-Cain and Daisuke Kawata were present as facilitators for this test workshop. A member of Wetherby Senior School staff was also present for safeguarding reasons and to provide observations. We present the execution of the test workshop and our findings in this section.

4.6.1 Comparison of participants with A New Direction's alumni

We recognise that there are significant demographic differences between the participants of the test workshop and the alumni of AND who responded to

our survey in Sec 3.3. However, there are still many similarities between the two groups. This includes the highest (planned) science education level and age, as all participants of the test workshop were age 18 and AND's target audience is 18-25 year-olds.

We compared the initial attitudes of the participants of the test workshop to the alumni of AND who responded to our survey (see Secs. 3.3.3 and 3.3.4) so we could assess how much of the feedback we were given by the test workshop could be applicable to a course for AND. We asked the same questions to assess participants' attitudes, which can be found as questions 5-12 of Appendix A.

We found that the participants of the test workshop had more positive attitudes towards science and maths than the responders to the AND alumni survey. All participants of the test workshop either agreed (3 people; 50%) or strongly agreed (3 people; 50%) with the statement "I am interested in science" whereas two people (12.5%) who answered the AND alumni survey disagreed with this statement and a further one (6.3%) neither agreed nor disagreed. Furthermore, when asked how they feel about science and maths, all participants of the test workshop expressed positive opinions about both subjects. Fewer responders to the survey of AND alumni had positive opinions of science and maths; 11 of 15 (73.3%) expressed positive experiences of science and eight of 15 responses (53.3%) reported positive feelings towards maths.

Interestingly, there was no mention of astrology or spirituality by any of the participants of the test workshop whereas this was a common theme among answers from AND alumni. This could potentially be because astrology and horoscopes are typically seen as more female, and there was a large proportion of responders to the survey who identified as female.

There are similarities in the attitude towards astronomy between the participants of the test workshop initially and the responses to the survey of AND's alumni. Five (33.3%) of the responses gathered in the survey of AND alumni stated that the responder was unsure of any ways which astronomy affects their life. Three (50%) of the participants of the test workshop were also un-

Group	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)
AND alumni surveyed	25	50	25
Test workshop participants	33.3	33.3	33.3

Table 4.1: **The initial responses from the survey of AND's alumni (16 people) and the participants of the test workshop (6 people) when asked *How much do you agree with the statement "I am interested in astronomy?"*. The distributions of answers are similar in both groups, showing that there are similarities between the two groups even though there are some significant demographic differences.**

sure of how astronomy affected their lives. Three (20%) responders to our survey of AND alumni mentioned astronomy has an effect on technology and two (13.3%) mentioned that astronomy contributes to climate change research. Two (33.3%) of the participants of the test workshop also mentioned astronomy's impact on technology and two (33.3%) mentioned astronomy has an impact on wider scientific research, though were not specific about the subject.

When both groups were asked how they feel about astronomy, three of six (50%) participants of the test workshop and eight of 15 (53.3%) of AND's alumni expressed positive attitudes. Furthermore, two of the six (33.3%) of the participants of the test workshop and three of 15 (20%) responses to the survey expressed a desire to learn more about astronomy. Finally, when asked *How much do you agree with the statement "I am interested in astronomy?"*, we found similar distributions in initial attitudes between the responders of our survey of AND's alumni and the participants of the test workshop. The distribution can be seen in Table 4.1.

4.6.2 Workshop execution

Due to the availability of the participants, we had 70 minutes to run this test workshop. Therefore, we omitted the break and the time for participants to complete the feedback survey during the workshop. Additionally, the participants were already familiar with each other, as they are in the same school and

shared some classes, so we reduced the allocated time for the introduction.

The icebreaker about exoplanet features seemed well-received, with all of the participants engaging with the idea, inventing creative, varied ideas and showing interest in the other participants' and facilitators' responses.

10 minutes was allocated for the discussion element of the workshop (based on the question "Why would we send something into space?") and participants were split into two groups of three with one facilitator. Initially, participants began by discussing astronomical research applications, such as telescopes and rovers. After that, mentions of human spaceflight and other science, such as general relativity and nuclear fusion, were discussed. Some ideas which are potentially inspired by science fiction were also mentioned, such as collecting resources and fuel from space or finding alien life. Prompting by the facilitators was required to bring the up topics outside of scientific research, but participants were still aware of related topics. This includes some technologies using orbiting satellites - including Starlink which was mentioned by name - and tracking the motion of storms and hurricanes. We found that this discussion did not take the full 10 minutes, potentially because there were only three participants in each group, so we moved on to the shared experience of watching a video demonstrating the law of gravity over planetary and stellar scales. Participants seemed to be interested in this and asked several questions about stellar dynamics.

The production portion of the workshop, where participants could use Scratch to model a planet moving around a star, saw all of the participants engaged throughout. During this portion, the facilitators moved between participants, giving one-on-one guidance on how to work with Scratch as none of the participants had used it before. Participants took several different approaches to tackling the task. This included manually moving the planet to find the desired coordinates and then putting them in the code, using more familiar technology - a calculator - to help them describe the motion of the planet, or by coding the equation of a circle or ellipse. We decided to show the code, de-

scribed in Sec 4.4.3.5, about 5 minutes in to this section rather than at the end. We found that this gave participants a better idea of what they could do with Scratch and how astronomers might use coding in their work. When shown our code, many of the participants switched approach to try and replicate that code. However, there was not enough time in the workshop to create the full model. We shared this code with them as further information at the end of the session.

Participants were then given 3 minutes to reflect individually what they gained from the session. They were given time after this to share these reflections in two groups of three participants and a facilitator. Participants shared a range of responses, including learning to use Scratch for the first time, the chance to think about the universe, realising ways in which astronomy can affect individuals' lives, and learning new things about astronomy. The participants seemed supportive of each others' answers and generally agreed with the statements brought up. The reflections portion took less than the 10 minutes allocated to it, which again may be due to the small groups.

With the final three minutes of the session, we gave participants time to ask the facilitators questions about astronomy and research. This was decided upon based on the feedback to the co-creation session, described in Sec. 3.5.1, where those participants wanted to know more about the facilitators' work. The questions asked here were about the motivation behind this workshop and what it is like being an astronomer.

4.6.3 Results of the test workshop

4.6.3.1 Reflections

From our observations, the workshop seemed to be well received by the participants. They stayed focused and on task throughout the duration of the workshop, and were contributing their thoughts and insights with confidence to both the facilitators and other participants. There was some discussion of the links participants to their previous learning in school lessons. This included seeing how Newton's law of gravity of and Kepler's laws of planetary motion

- which they have learned in physics classes - can be applied to show a planet moving. There was also discussion of what examples of coding were used in a computer science GCSE and how participants would have liked to see more science applications like this in their lessons.

We found it beneficial to be an in-person workshop for this test. Being in the same room as the participants made it much easier to judge when they were coming to the end of their discussions so we could move on to something else and make best use of the time we had. It would have been much harder to judge the timings if we were using virtual breakout rooms. Furthermore, it was easy to move around the room and quickly give help to participants as they started using Scratch, which would have been much harder to do quickly in a virtual workshop. This would likely have meant that the coding section of the workshop would have been less productive as participants would have had to wait for facilitators' time, and could lead to more frustration at the activity.

4.6.3.2 Workshop feedback

Participants were given five questions in a survey after the workshop to obtain their feedback about the workshop in addition to the questions assessing their attitudes towards science and astronomy. These questions can be found in Appendix A.3. When asked what they gained from this workshop, five participants (83.3%) mentioned astronomy knowledge, coding knowledge or the link between astronomy and coding. The other student simply answered "enjoyment". These answers indicate that two of our objectives (have a positive experience of astronomy and have a go at programming in Scratch; see Sec. 4.4) were achieved by participants. Our question asking for skills and knowledge developed received similar answers to the previous question; three participants stated an astronomy fact they had learned, and three mentioned gaining knowledge of how to use Scratch. Participants who gained skills in using Scratch did not explicitly relate this to coding or programming in general, which could be an aspect which should be emphasised more by the facilitators. When asked what they liked about the workshop, participants mentioned a specific part

of the workshop such as the discussion (two mentions; 33.3%) or the coding element (four mentions; 66.7%). In addition, one student said that they appreciated that there was "the freedom to create what u wanted in your own way", which is encouraging as this aspect would be appealing to the people interested in the cultural sector, who this workshop was designed for. This sentiment also fits with the theme of agency and respect which was seen in the responses from the co-creation session.

In both questions asking for ways to improve the workshop, participants asked for more information about astronomy; this was suggested by five of the participants (83.3%) when asked how to improve the workshop and three (50%) when asked what should have been emphasised more. This feedback is interesting, and it would be valuable to know if this desire for more astronomy was because participants felt more interested in astronomy after the workshop, or because they expected the workshop to be focused on astronomy (rather than on skill development) when they joined. Further evaluation into this, such as interviews or focus groups, would be useful in providing more insights, including how this could be improved (Reed et al., 2018). It would also be interesting to see if a similar attitude was shown by people who work with AND, or if the desire for more astronomy is greater among the test workshop participants because of their more positive attitudes towards science as discussed in Sec 4.6.1.

In addition, there were two mentions (33.3%) about how the coding section could be improved. One stated that there should be more guidance available and the other stated that there was too much time spent on this and it was their least favourite part of the workshop. One participant (16.7%) stated that the workshop should be faster paced so that we could include more content. However, given that there was also the demand for more guidance on coding, it would be harder to move at a faster pace. Finally, one participant suggested that we emphasise "the purpose of the workshop" more. This would be a useful change to make, as it can help to focus the participants and facilitators more

on the skill and knowledge development aspect of the workshop.

We asked the member of Wetherby Senior School staff present to observe how the participants interacted with our workshop. As one of the teachers at the school, the member of staff knew the participants much better than the facilitators so was able to make valuable observations of how participants acted and compare these to their normal attitudes. The questions we asked the member of staff can be found in Appendix A.4.

The teacher observed that the participants engaged more with the workshop than they would in a normal lesson, and that participants were contributing and asking questions more than in a normal lesson. In particular, he noted that the participants were asking a lot of questions after viewing the video showing the planets' orbits around the Sun and the Sun's motion in the Milky Way. This shows the participants engaging with the video and following the aim "to understand that the laws of physics work the same way on different scales" (Sec. 4.4). It was noted by the teacher that the participants appreciated being able to talk to graduate scientists to ask wider questions about the field than they would normally get to in class. The suggestions to improve this workshop were to make it longer, which would be difficult due to availability, and to offer more solutions showing differing ways to approach the coding task. We could have done this by creating other ways for the students to interact with the code, either by creating examples showing the planet moving using the equation of a circle or an ellipse, or sharing the full Scratch model described in Sec. 4.4.3.5 and giving participants a chance to experiment with the initial conditions of planet to see what orbits that creates.

We were also informed by a teacher at Wetherby Senior School that in the week following the test workshop, some of the students had been experimenting with Scratch in their free time. Some had spent more time on the planetary orbit as presented in the test workshop. Others had experimented with some variations of it, such as creating a system of two planets and a star. Participants' choice to spend their own time to continue the test workshop activity

shows that it had impact on the students and was well received. The ability to use Scratch to experiment also gives participants the opportunity to further develop the skills which they started to work on during the workshop, deepening the impact of this standalone workshop.

4.6.3.3 Attitudes to science and astronomy

We asked questions to assess participants' attitudes to science and astronomy before and after the test workshop. These were questions 5-12 of Appendix A. As this workshop was a one-off intervention, we were not expecting to see much change in participants' attitudes, since research shows that standalone activities make little long-term change in attitudes (e.g. Archer et al., 2021).

We found that there was no change in our participants' attitudes towards science and maths; participants feelings and interests remained positive towards both subjects. There was also no observed change in how up-to-date participants felt about science or how comfortable they felt in scientific environments. This matches our expectations of the effect of our session, especially as we did not explicitly focus on general science or maths topics. There were some small changes in the responses to the question *How much do you agree with the statement "I am interested in astronomy"?*. Before the workshop, answers were evenly divided between "strongly agree", "agree", and "neither agree nor disagree" with two out of six (33.3%) responses to each. After the workshop, four participants (66.7%) agreed with this statement, one (16.7%) strongly agreed and one (16.7%) neither agreed nor disagreed. This shows a small amount of change on an individual basis but no difference for the group as a whole.

However, we did see qualitative changes in participants' attitudes towards astronomy change to be more positive after the test workshop. Before the test workshop, three (50%) of participants expressed positive answers when asked *How do you feel about astronomy?*, which feelings the subject was interesting or important. One participant (16.7%) explicitly stated that they felt "neutral" towards astronomy before the test workshop. However, after the workshop, all

participants expressed positive views of astronomy.

Participants also showed a more diverse range of answers to the question *What is the first word you think of when you see the word "Astronomy"?* after the workshop. Before the workshop, five (83.3%) participants answered "stars" and one (16.7%) answered "universe". After the test workshop, each participant gave a unique answer: "universe", "space", "learning", "stars", "orbits", and "endless possibilities". It is encouraging to see "learning" as one of the answers given, as the aim of the workshop was to develop skills and knowledge through astronomy. This answer is supportive that the general aim of this test workshop was achieved. It is also interesting to see that there was a more diverse pool of answers given by the participants of the test workshop afterwards, whereas the participants of the co-creation session showed a less diverse range of responses with three (75%) answering "space" and one (25%) answering "stars". This difference could be because there was more astronomical content in the test workshop than the co-creation session, and so participants were exposed to a more diverse range of astronomical concepts.

One of the aims of the test workshop was to give participants more of an understanding of how astronomy can be relevant to everyday life (see Sec. 4.4). To test this, we asked participants both before and after the test workshop the question *How do you think that astronomy affects your everyday life?* Before the test workshop, three (50%) of participants said either that they didn't know or that astronomy had little affect on them. The other three participants (50%) stated that astronomy has an impact on them through technology and/or a broader effect on science. After the test workshop, all participants gave answers saying that astronomy affects them through technology - explicitly stating satellite communication, which was discussed during the workshop - or stating that astronomy has an impact on broader scientific areas and how we perceive the world. This shows that our workshop has achieved the aim of increasing understanding of how astronomy relates to everyday life. The relation to participants' own lives is also likely to give the workshop a greater,

more lasting impact on their attitudes towards science and astronomy (Archer et al., 2020) which is encouraging.

4.7 Impact on A New Direction

In a discussion with D. Mayaki of AND, she stated that the period when we work with the charity was a time when they were actively looking into ways they could start co-designing and co-producing content for their cohorts. Our co-creation session, discussed in Sec 3.4, helped to inform AND's thinking and approaches to co-production, and has embedded co-creation in their standard practice. Additionally, our collaborative work has helped AND grow confidence in working on areas outside where the charity has expertise.

The workshop presented in this chapter, the results of its evaluation, and information required to run it without needing prior knowledge in astronomy or coding has been shared with AND. This allows the workshop to be used and developed by AND in the future, embedding our work in AND's practice, allowing for further testing and evaluation, and ensuring the workshop can be used as it was designed; to develop transferable, career-relevant skills using astronomy as an inspirational context.

Chapter 5

Conclusions and future work

5.1   Conclusions

5.1.1   Neural Network Studies of Galaxy Evolution

In Chapter 2 we presented a proof of concept study of an application of a Convolutional Neural Network (CNN) model to recover age and metallicity of nearby galaxies. The data used in this work is taken from the CALIFA dataset and is synthesised to produce data resembling 36 J-PAS-like photometric bands which were used to train a CNN model. A total of 21,230 spectra from 190 galaxies are used in this analysis.

We have demonstrated that the CNN model is able to predict age and metallicity values on a relatively small proportion of the training set provided that it has enough high quality data to cover the range of stellar populations present in the application set. We show our models are not strongly affected by the galaxy's star formation rate, relative bulge size, inclination angle or extinction. This, along with the low computing power required to apply the trained model to new data, makes CNNs a suitable method of analysis for large datasets such as those that will be produced by the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS).

The CNN was able to predict age and metallicity accurately in the ideal case of Set A (Sections 2.4.1 and 2.4.2), where the data used in both the training and application sets came from spectra from different regions of the same galaxy. The

recovery for age and metallicity is excellent and has a robust standard deviation of 0.03 dex. The radial gradients of age and metallicity are calculated from the Calar Alto Legacy Integral Field Area (CALIFA) survey's spectroscopically derived age and metallicity, and the CNN predictions of these values for each galaxy. The robust standard deviation of the difference between the gradients with spectroscopically derived values and the CNN predicted values is 0.02 dex/R_e for both age and metallicity. Radial gradients are also recovered well with the CNN.

On the other hand, for the more realistic case of Set B (Section 2.4.3), where the training and application datasets are composed of spectra located in different galaxies, the CNN's recovery of age and metallicity is markedly worse. The robust standard deviation for the recovery in Set B is a factor of ~ 7 worse for age and ~ 8 worse for metallicity than Set A. There is also a significant degree of difference between the radial gradients derived from the spectroscopically measured values and those calculated using predictions from the CNN trained using Set B, due to the greater dispersion of CNN predictions for each spectra. We attribute this decrease in prediction accuracy with respect to Set A to the lesser degree of similarity in stellar populations between different galaxies compared to different regions within the same galaxy. This is supported by the smaller error in recovery for early-type galaxies compared to late-type galaxies in Set B, as the latter have a greater diversity of stellar populations. Our dataset contains a relatively small number of galaxies, which was not enough to account for the vast diversity of stellar populations.

Constructing a large enough high-quality training dataset to improve machine learning models is crucial. Therefore, we will continue to need additional large spectroscopic surveys and high-performance spectral fitting codes. More high quality spectral (preferably integral field unit; IFU) data and sophisticated stellar population models to fit these spectra would be invaluable for creating a high quality training set for further neural network studies. The efforts in increasing the coverage of IFU surveys, such as SAMI (Croom et al., 2012) and MaNGA (Bundy et al., 2015), and their improving fitting pipelines will be essential in future applications of CNNs to situations similar to that of Set B in this work. Additionally, the use of

synthetic spectra from simulated galaxies with a large range of evolutionary histories could also be used, in combination with transfer learning (Zhuang et al., 2019), to improve the accuracy of predictions in the future.

5.1.2 Astronomy Inspired Skill Based Learning

In Chapters 3 and 4 we explored the use of astronomy as vehicle to develop skills and interest in science. We worked with jobseekers, a new audience who are not usually targeted by public engagement schemes. In particular, our participants were looking for work in the cultural and arts sectors. We held a co-creation session to find out how best we could engage our participants with astronomy through the development of career-related and transferable skills. Recognising the essential role intermediaries play, we worked in partnership with A New Direction (AND), a cultural sector employability charity, and their alumni.

We used the results of our online survey to investigate the relationship between jobseekers in the cultural sector and astronomy. We have found that our participants are generally receptive to and interested in astronomy, though they are not particularly connected to the subject at the moment. We also assessed indicators of jobseekers' science capital. The results showed that our participants have an estimated science capital lower than the national average. However, we found that our participants talked about science with others more frequently than the national average which is a sign that their science capital can be supported and developed. This suggests that if we work to make science more equitable and accessible, as we have suggested in Chapter 3, that people who do not currently engage with science may begin to feel welcome.

Following the survey we ran a 90-minute co-creation session with AND alumni to discuss topics relating to the format and content of an astronomy-based skills course and collaboratively created a 90-minute pilot workshop. We found that our participants are most interested in the stories that can be told with and through astronomy or space science. Additionally, our participants has made it clear that they wish to be treated with respect and given agency over what and how they develop skills in our workshops. To work well with jobseekers, we have used these themes

to guide the creation of our workshop. Furthermore, the participants reported feeling that they mostly gave information during the co-creation session and wanted a section where they could learn about astronomy so they would gain something from the session too. This is an important aspect to consider when organising future co-creation sessions.

Building on the knowledge we gained from the co-creation session and its associated survey, we created a 90-minute pilot workshop to fulfil the wants and needs of AND's alumni. The workshop structure and content is presented in Chapter 4. We found that the co-creation element has been very helpful in prioritising the needs and views of our participants. The workshop focuses on developing discussion and programming skills for the participants and uses the astronomical topic of orbits to engage participants. In addition to developing these skills, the aims for the workshop also include demonstrating how astronomy relates to the daily lives of participants and how their experiences relate to astronomy, and for participants to have a positive experience of astronomy. The latter is targeted because we hope to increase the level of comfort and confidence of the participants around astronomy and science which may lead to them engaging more with science in their futures.

5.2 Further Work

5.2.1 Neural Network Studies of Galaxy Evolution

5.2.1.1 Application to real data

The next step to further develop our neural network model would be to apply the method developed in Chapter 2 to real data. This could be done using the Advanced Large, Homogeneous Area Medium Band Redshift Astronomical Survey (ALHAMBRA survey, Moles et al., 2008) as our application set. ALHAMBRA is a medium-band photometric survey, with its 20 non-overlapping bands separated by 300 Å (Aparicio Villegas et al., 2010). These filters are three times wider than the filters in the J-PAS survey, used in Chapter 2, which consists of 56 overlapping bands. Alternatively, the MINIJ-PAS survey (Bonoli et al., 2021) used a smaller, lower spatial resolution camera than the full J-PAS survey to examine a $1\,\mathrm{deg}^2$ area

of the sky. This dataset could be more appropriate as it uses the 145 Å filters that we used to train our CNNs.

The CALIFA survey can continue to be used as the training set for the CNN, with mock-ALHAMBRA data synthesised from the CALIFA IFU data. As in Chapter 2, this allows us to use accurate, spectroscopically determined labels for age and metallicity, which the CNN will learn to derive from the mock data. This should aid in increasing the accuracy of predictions from the medium-band photometric data.

The challenges expected from this project include the increased photometric band width, and effects of using real data. As there will be fewer bands in the mock-ALHAMBRA data compared to the mock-J-PAS data, we expect that the accuracy of recovery of the CNN will decrease. This will be due to the loss of information as the SED resolution decreases. Real ALHAMBRA data will be noisy, which was not the case with the mock data used so far. Additionally, the effects of the point spread function (PSF) have not been considered so far. Both of these properties of the data are likely to increase the error in the CNN predictions.

5.2.1.2 Evolution at $z < 2$

The evolution of galaxies outside the local universe are also of interest, as it allows us to determine how galaxies evolved at earlier times. This could be done by applying the CNN model from Chapter 2 to a dataset constructed using a combination of data from the Survey for High-z Absorption Red and Dead Sources (SHARDS, Pérez-González et al., 2013) and 3D-Hubble Space Telescope (3D-HST, Momcheva et al., 2016) survey.

The reasoning behind using two datasets in combination is that there is not a single survey that observes galaxies up to $z = 2$ that has both high spatial and spectral resolution. Therefore, we could use the 25 medium-band photometric survey SHARDS to determine age and metallicity values accurately for each galaxy on a large spatial scale. We can then use the fine spatial resolution of 3D-HST and its grism SED, combined with the limits derived from SHARDS, to obtain accurate values of age and metallicity at each HST pixel.

5.2.2 Astronomy Inspired Skill Based Learning

5.2.2.1 Feedback on the workshop

Our workshop, presented in Chapter 4, would benefit from feedback from AND staff. The charity has a wealth of experience in creating opportunities to develop career-relevant skills for jobseekers and they know what activities and techniques are successful for their participants. Their expertise could help us to improve the pilot workshop further to make it more engaging and effective in helping to develop the skills that our participants have chosen.

5.2.2.2 Delivery of the workshop

The next step in this work is to deliver the co-created workshop we developed in Chapter 4 to jobseekers. This will allow us to test what aspects of our co-designed pilot workshop work well, and which areas can be improved. To do this, we would look to work with a group of people who are currently taking courses or interacting with AND. Some of the alumni who took part in our co-creation session also expressed interest in participating in the pilot workshop they co-designed, and these people could be a valuable resource to feed back to us on how we applied their thoughts in the workshop.

Evaluation should feature heavily in this session. The pilot workshop will investigate what methods are the most suitable and effective for developing career-relevant skills before a longer term course is developed. Therefore, feedback from the participants will be essential. We will be looking for their reflections on how engaging the activities were, how interesting the astronomy topic chosen was and any impact on participants' attitudes to science. Using participants' views to develop and improve the course continues the ethos of co-creation we began with the design of the pilot workshop.

5.2.2.3 Course development

We aim to use the evaluation from the workshop presented in Chapter 4 to inform the design of a career-relevant, skills-based course for jobseekers where astronomy can be used as an inspirational vehicle. Therefore, we have identified aspects of

the pilot workshop where we would like participants' feedback. This includes the content of the workshop, how effective they found it and whether they felt that the astronomy component was beneficial. In addition, we have compared out pilot workshop to equity and teaching best practice literature to identify ways in which we can improve our course.

The course could be improved over the standalone workshop presented in Chapter 4 by doing more to challenge the status-quo of science and how our participants relate to it, and finding ways to engage the wider community rather than just those who come to the workshop. The course will be an improvement over the workshop by being a longer-term event, which has been shown to demonstrate a larger impact on their lives (e.g. Archer et al., 2021, 2020). With these adjustments, we will be able to make a course that is equitable, able to provide for the needs of jobseekers and inspires our participants to connect with astronomy.

Appendix A

Survey questions & results

The full questions and data for the surveys can be found below.

A.1 A New Direction (Create Jobs) Alumni - UCL Astronomy Questionnaire

1. Which skills or knowledge would you be interested in gaining from a course? Select all that apply

   (a) Spreadsheet use (e.g. using formulae and manipulating data)

   (b) Programming (e.g. how to write Python programs)

   (c) Data handling (e.g. finding out information from sets of data)

   (d) Collaboration

   (e) Problem Solving

   (f) Astronomy

   (g) Maths

   (h) Other

2. What barriers do you see that could prevent you or other people taking part in as astronomy-based skills workshop?

3. What discussion/conferencing platforms would you be happy to use for a focus group meeting? Please select all that apply.

    (a) Zoom

    (b) Skype

    (c) Teams

    (d) Google Hangouts

    (e) Phone Call

    (f) Blackboard Collaborate

    (g) Twitch

    (h) Discord

4. What collaboration/note-taking platform(s) would you be happy to use for the focus group meeting? Please select all that apply.

    (a) Miro

    (b) Google Docs

    (c) Jamboard

    (d) Sharepoint

    (e) Mural

    (f) Padlet

    (g) Gather.town

    (h) Remo

    (i) Other

5. What is the first word you think of when you see the word "Astronomy"?

6. How do you think astronomy affects your everyday life?

7. How much do you agree with the statement "I am interested in astronomy"?[1]

8. How do you feel about astronomy?

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[1]A 5-point Likert scale (Likert, 1932) was used for this questions.

9. How do you feel about science?

10. How do you feel about maths?

11. How much do you agree with the following statements?

    (a) I am interested in science.[1]

    (b) I am up-to-date with scientific news and discoveries.[1]

    (c) I enjoyed science at school.[1]

    (d) I feel comfortable in places where science is discussed and practised (e.g. museums, laboratories, science centres)[1]

12. How often do you talk to friends, family or colleagues about science or science-related topics?

    (a) Never

    (b) Once a year

    (c) A few times a year

    (d) Once a month

    (e) Weekly

    (f) Nearly every day

13. What gender do you identify as?

14. What ethnicity are you?

    (a) White

    (b) Mixed or Multiple ethnic groups

    (c) Asian or Asian British

    (d) Black, African, Caribbean or Black British

    (e) Arab

    (f) Other

15. Which of these best describes your highest level of education?

    (a) No qualification

    (b) 1-5 GCSEs

    (c) More than 5 GCSEs

    (d) BTEC Firsts (level 1-2)

    (e) NVQ 2

    (f) A levels/IB

    (g) NVQ 3

    (h) BTEC Nationals (level 3)

    (i) HND

    (j) NVQ 4-5

    (k) Degree

    (l) NVQ 6

16. What is the highest science or engineering qualification you have or are currently studying for?

    (a) No qualification

    (b) GCSEs

    (c) BTEC Firsts (level 1-2)

    (d) NVQ 2

    (e) A levels/IB

    (f) NVQ 3

    (g) BTEC Nationals (level 3)

    (h) HND

    (i) NVQ 4-5

    (j) Degree

    (k) NVQ 6

17. Do you have any access requirements, such as regular breaks, text-light, colour palettes, transcript of the session etc?

A.2   UCL-A New Direction Co-Design session final thoughts

1. How much do you agree with the following statements?

    (a) I felt able to express my views during the session.[1]

    (b) I felt my views were listened to and taken on board during the session[1]

    (c) I am happy with the outcome of the session.[1]

    (d) I enjoyed taking part in the session.[1]

2. Please elaborate on any of the above questions if you would like to.

3. What were the two best bits of the session?

4. What could we have done to improve the session?

5. Is there something that you think we missed when we designed this workshop together? Such as another skill or topic you'd like to see included.

6. Do you think you'd find taking the workshop we developed enjoyable and valuable? Why?

7. What is the first word you think of when you see the word "Astronomy"?

8. How much do you agree with the statement "I am interested in astronomy"?[1]

9. How do you feel about astronomy?

10. Is there anything else you'd like to tell us?

A.3   Feedback questionnaire for participants of the test workshop

In addition to questions 5-12 of Sec A, we also asked the following questions to the test workshop participants to obtain their feedback.

1. **What did you gain from the workshop?**

2. **What skills or knowledge did you develop or gain during the workshop?**

3. **What did you like about the workshop?**

4. **What could we have done better to improve the workshop?**

5. **What should we have emphasised more during the workshop?**

A.4   Teacher observation questions

The following questions were given to the member of Wetherby Senior School staff who was observing the workshop.

1. **Did the students seem more, less or similarly engaged in this workshop compared to a normal lesson?**

2. **Did the students contribute more, less or similarly compared to how frequently they would contribute in a normal lesson?**

3. **What was special about this workshop that students wouldn't gain from a normal lesson?**

4. **What changes would you make to the workshop to help the students get more out of it?**

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