Meteorological training for the digital age: A Blueprint for a new curriculum

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Abstract
Almost all professional meteorologists take part in meteorological training during their undergraduate or graduate study or professional job training in the public or private sector. Increased benefits can be accrued by employers and employees, if this training is based on the same underpinning skills and attributes, aimed to equip people entering meteorology for the wide range of future roles they might undertake.

While there is a great deal of excellent, innovative practice in our community, the time is now right to look again at the nature of the meteorological curriculum. Meteorology faces significant challenges in the 21st century to deal with the twin challenges of increases in the number and severity of extreme weather events and the increased complexity of forecasts demanded by end-users.

Here, a blueprint which describes a number of key principles which should be used to design, evaluate and enhance curricula for students entering our field in the next 10 years is proposed. The blueprint does not discuss in detail the core mathematical and physical principles which underlie any high quality training in meteorology but rather focuses on the key skills and attributes needed to make the next-generation of meteorologists innovative and effective which include:

- Meteorological competencies,
- Personal and inter-personal attributes,
- Core skills as a scientist and
- Ethical and professional interaction with broader society.

The blueprint is intended to encourage debate about how we equip new meteorologists for the digital age. We plan to use these principles to review and enhance our own curricula in the near future.

Introduction

Below we set out fourteen key principles to underpin meteorological training for those entering our profession over the next ten years. We think that a curriculum that follows these principles will develop the skills and attributes needed by meteorologists as they begin their professional careers and develop into the leaders of our field in the middle decades of the 21st century. Often, the skills and attributes developed in our curricula are defined separately for University courses and for continuing professional training delivered by Meteorological Services and other providers. While this is understandable, we think that a fundamental opportunity to define and deliver a coherent training programme across all forms of meteorological education is being missed. For this reason, we decided to work together to write this blueprint which sets out fourteen needs for meteorologists that, together, a complete educational programme should provide. The skills and attributes are relevant to all forms of training in meteorology, for students at University, for those undertaking Continuing Professional Development (CPD), and for those learning via Open Online Courses (OOCs).

Throughout the blueprint, we refer to those engaged in education and training as learners, for lack of an alternative term to cover those new entrants to Meteorology at any point during the first 10-15 years. Fundamental to a coherent blueprint for this period is the ability for different education and training providers to work towards providing students with a set of skills to enable them to succeed in a challenging work environment for Meteorology. It would be unrealistic to expect that each of these skills could be covered in the same depth and breadth in every separate part of a student's education and training, and there would not be the time or expertise to do so. This, however, only increases the need for a recognition of the shared and distributed nature of training for meteorologists. To develop effective people, education and training should work together toward a set of shared principles as outlined in our blueprint.

The middle decades of the 21st century will be a time of critical challenge for our profession since, even with limited mitigation, the impacts of climate change will be clear and progressing in most regions (Hawkins and Sutton 2012). The likely concurrent changes to extreme weather events (Field et al. 2012) will place meteorological forecasting on all timescales in a critical societal position. There will also be significant opportunities, through the huge improvements in the accuracy of weather forecasts (Bauer et al. 2015), for meteorology to continue in new and exciting ways to society. One example is the growth of an efficient renewable energy sector (Frei et al. 2013) where accurate forecasts on a range of timescales from days to seasons ahead are increasingly critical. There will also be new opportunities for forecast and understanding the atmosphere brought about by embracing continuing increases in computing power (including perhaps new technologies like quantum computing (Debnath et al. 2016) and dense, real-time environmental sensor networks exploiting internet connectivity).

We do not intend the blueprint to be prescriptive about curricula content, style or delivery. However, we believe it will be increasingly important that training across the sector is approached in a systematic, integrated way underpinned by the professional accreditation for meteorologists offered by learned societies in many countries. We choose not to focus on the essential meteorological, mathematical and physical content of training in atmospheric science both because this is covered extensively in, for example, the World Meteorological Organisation, Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology (2015).[1]

Instead, our blueprint covers four sets of key skills for meteorologists which cover:

- Meteorological competency [principles 1 & 2],
- Personal and inter-personal attributes [principles 3,4,5 & 6],
- Core skills as a scientist [principles 7, 8,9, 10 & 11] and
- Ethical and professional interaction with broader society [principles 12,13 & 14].

When we refer to 'Meteorology' or 'Meteorologists' we mean anyone who works as a professional in atmospheric science. Our first principle highlights our belief that individual meteorologists will move between roles with a focus on research and development, operational delivery and consultancy over the course of their career and may move frequently between employers in the public, private and University sector. An important motivation for the blueprint is the flexibility of future careers for meteorologists and the need to provide training that is portable, generic and easily upgradable.

Our Blueprint

Meteorological training should prepare meteorologists to:

1. Move between roles which involve research and development, operational delivery, consultancy or a combination of the three.
2. Be comfortable discussing and thinking about weather and climate on a range of timescales from days to decades.
3. Be responsible for their own continuing professional development and facilitating the personal development of their colleagues.
4. Be resilient to a changing working and resource environment and confident in embracing new challenges.
5. Critically evaluate scientific literature.
6. Be aware of the benefits and opportunities of open distribution of scientific knowledge, software and data.
7. Be able to develop transparent, robust and well documented scientific software.
8. Be able *to work in teams that develop scientific models and modelling systems which produce estimates of the real-world impact of meteorological variability.*
9. Be able to appreciate and evaluate the information available through observations and measurements.
10. Be competent in designing statistical tools and applying statistical thinking to the atmosphere.
11. Be able to ensure that operational standards and quality are maintained within increasingly automatic systems.
12. Be able to effectively understand and communicate risk and uncertainty.
13. Be clear in expressing their work in the context of contradictory forecasts or interpretations.
14. Be able to interpret their work in the context of a changing climate.

[1] Similar statements for suggested content for the American Meteorological Society can be found here (American Meteorological Society, 2017a & Royal Meteorological Society 2017a)

Evidence base

Principle 1: Meteorological training should prepare meteorologists to move between roles which involve research and development, operational delivery, consultancy or a combination of the three.

Roles within meteorology can be largely classified into one of three areas – research and development, operational delivery and consultancy, differentiated by their depth and the frequency of application of different skills. Driven and aided by a focus on productivity and improvements in the accessibility and capability of supporting technology, there are already indications in the working environment, that there is a requirement for a merger of the skills between each area.

Numerical Weather Prediction (NWP) has increased forecast accuracy significantly in the last 30 years, with approximately a day's improvement in skill every decade (Bauer et al. 2015). The trajectory of improvement in NWP has meant that discussions on automation of production of weather forecasts are becoming the norm. The value which a human operational meteorologist adds is becoming increasingly specialised to localised and short range events and the understanding and communication of the associated risk, vulnerability and impact.

The change in emphasis in production methods for traditional forecast services, alongside improvements in computational availability, means that the role of the operational meteorologist will change. Human customer contact is still expected in the form of decision support and this has been demonstrated to be invaluable (Wall et al 2017).
However, there are already indications that the role of the meteorologist will change from one of direct forecast provision to one of general decision advice.

To be considered a meteorological expert, a greater understanding of the underlying capabilities of a variety of competing NWP models will be required. The depth of this understanding may vary according to the role being fulfilled. For example, in order for an operational meteorologist to decide how best to use the forecasts available to drive automated forecast production an in depth understanding of a number of numerical models will be required. This is akin to that which is needed to develop models in the first place, a role traditionally held by scientific researchers. In addition to this, they will require an in-depth level of understanding of meteorological processes and build on their knowledge of the importance of observational data to these processes, such that they have an ability to assess the current atmospheric state and forecasts produced by NWP systems, combining the role of operational meteorologist and researcher. In the future, operational meteorologists embedded in a customer environment may be required to work collaboratively with local experts to develop an impact model or decision aid using local software. The operational meteorologist thus decides which NWP data stream to use within this model, combining the role of scientific consultant with operational meteorologist.

There is no doubt that there will still be a role for specialists, but the changes in technology enabling localised model development and automation which could be expected in 20 to 30 years time and the expected continuation of focus of organisations on efficiency and productivity which resulted from the 2009 financial crisis (Patterson 2012; PwC 2014), will likely lead to operational meteorology jobs which require skills from all three of the traditional roles.

Principle 2: Meteorological training should prepare meteorologists to be comfortable discussing and thinking about weather and climate on a range of timescales from days to decades.

The continued pursuit of increased accuracy in long range weather forecasts (monthly to seasonal) has demonstrated improvements in skill which are now making forecasts on these timeframes usable (Scaife et al. 2014; Smith et al. 2016). Over the next 20-30 years, coupled with improvements in the communication of risk and uncertainty, it is expected that forecasts on these timescales will become increasingly integrated into end users decision making for planning, resourcing and investment. Furthermore, as the impacts of a changing climate become realised through the changes expected to “the frequency, intensity, spatial extent, duration and timing of” extreme weather and climate events (IPCC 2012), the requirement for meteorological advice on long timeframes will become more obvious to end users.

The creation of meteorological experts for all timeframes is perhaps unrealistic, but the requirement for individuals who are knowledgeable about multiple time and spatial scales is expected, including the ability to reference one in the context of the other (e.g. a series of intense hurricanes in the context of global modes of variability like ENSO).

*Principle 3: Meteorological training should prepare meteorologists to b*e *responsible for their own continuing professional development and facilitating the personal development of their colleagues.*

Further to principles 1 and 2, the multifaceted expert will be required to continue to develop skills in a number of different specialisms. It will be almost impossible to support this career path for individuals with a formal, classroom-based training programme. Moreover, as training materials become increasingly accessible via the internet, the responsibility for continuing professional development will lie with the individual, particularly as these multifaceted roles become increasingly embedded within the customer environment, and therefore more specialised according to customer application.

For most employers, there is a requirement for professional meteorologists to maintain their knowledge of the latest changes in their fields of expertise. The importance of accreditation after formal qualification through organisations such as the American Meteorological Society and the Royal Meteorological Society is likely to increase. This provides some assurance to both employers and customers that they are accessing the most current capability in their field. For the qualified individuals, it provides a structure for completion of continuing professional development (AMS 2017; RMetS 2017).

Continuing professional development, of course, does not just apply to professional expertise, but to core, transferable skills. Meteorologists can help themselves to progress towards more senior roles by developing and updating their skills . Specialist subject knowledge is an important but not exclusive determinant of effective leadership of people

(Mumford et al. 2017). The development of these skills requires self-awareness, the desire for self-improvement and an awareness of the importance of developing others. These underpinning competencies should form part of the underpinning curriculum of both academic and vocational learning.

Principle 4: Meteorological training should prepare meteorologists to be resilient to a changing working and resource environment and confident in embracing new challenges.

Over the last 20 years, the working environment in many different fields has been dramatically altered. Major changes in technology have changed how people communicate with each other and how organisations communicate with their customers and stakeholders. Communications technology has also enabled flexible working environments but has also led to increased expectation for employees around their availability for consultation outside traditional office working hours (Ouye 2011). It would be naïve to assume that periods of substantial or even disruptive change will not appear again in the next 20-30 years. The ability for an individual to respond to these changes, particularly future leaders in guiding their teams or department's response to this, will help define their future success.

To engender confidence in embracing new challenges, supportive training and awareness in strategic and organisation wide thinking, effective leadership, change management and project management practices (Prosci, 2016; Christensen & Overdorf 2000) should be considered complementary to the development of scientific understanding. These transferable skills will help individuals work in a number of professional roles and give them greater flexibility to change and manage their own careers.

Principle 5: Meteorological training should prepare meteorologists to critically evaluate scientific literature.
The importance of being able to critically evaluate appropriate scientific literature has been built into scientific research and consultancy best practice for many years. Indeed in order to become a credible scientist or consultant, the ability to discover associated scientific literature, recognise the relevance of it to the current topic of work and be able to attach appropriate credibility to the conclusions of the study is fundamental. The imperatives for enhancing a student's ability to critically evaluate literature stem from the increasingly complex and fluid world in which their future jobs will exist (Brew 2010), where knowledge is freely created and exchanged. In this world, approaches that emphasise the role of students as participants in the research, such as the research-tutored and research-based approaches outlined by Healey (2005) are particularly valuable.

Principle 6: Meteorological training should prepare meteorologists to be aware of the benefits and opportunities of open distribution of scientific knowledge, software and data.
Open access to scientific knowledge, software and data are fundamental to both the application of the scientific method and the future of global scientific capability. Meteorological science pioneered the open, international exchange of information through the International Meteorological Organisation, WMO and the World Weather Watch. Although there are increasing commercial and financial pressures on meteorological services, it is important that meteorologists are equipped to maintain and develop the open

nature of meteorological science (e.g. WMO resolution 40, https://library.wmo.int/pmb_ged/wmo_837_en.pdf#page=18)

Increasingly, open science is seen as an imperative for publically funded research and development (e.g. Finch et al. 2012, Tickell 2016). Technological advances make it increasingly easy to access information and therefore derive benefits from open data. Indeed, it is estimated that open data from all sectors could provide $3tn to $5tn a year of economic benefit across a number of different sectors (McKinsey, 2013).

Ensuring meteorologists are aware of the benefits and opportunities open access provides will enable them to become involved in applying their core knowledge to different areas of research and industrial or vocational application. As increasing amounts of data become openly available it will be important that scientists can manage and extract value from this data and that they make their work as broadly available as possible to others.

Principle 7: Meteorological training should prepare meteorologists to be able to develop transparent, robust and well documented scientific software.
As scientific software has become more complex, with multiple users at multiple organisations, transparent, robust and cheap software development has become a key working imperative (Wilson 2013). Many operational meteorological organisations have sophisticated version management systems in place for internal use but the use of similar systems in academia is generally more limited. Every meteorologist entering the field in the next ten years will be required to use software, but many will be required to develop software during their career, for which, developing the skills to ensure the transparency and robustness of their code will be an important professional competence. Indeed many journals already require software to be available for examination (e.g. Science 2017; Nature 2017).

Almost all academic meteorological training includes instruction in basic coding, numerical methods and running complex models. However, training in the principles of version control and software development or specific experience with freely available software like GitHub or Bitbucket is more limited. Specific evidence for this lack of formal software development training is the existence and popularity of the Software Carpentry (https://software-carpentry.org) and Data Carpentry (http://www.datacarpentry.org) organisations which seek to teach early career researchers these critical skills. These skills also link to the most recent NERC Most Wanted Skills report (NERC 2012) which highlights the shortage of environmental scientists with skills in modelling and data management.

Principle 8: Meteorological training should prepare meteorologists to work in teams that develop scientific models and modelling systems which produce estimates of the real-world impact of meteorological variability.
During the past decade, there has been an increasing focus within the meteorological community on delivering climate services which support decision-making. The Global Framework for Climate Services (2017) sets out principles by which our skill and expertise in monitoring and predicting the atmosphere can be applied to real-world sectors. Similar principles apply to the provision of meteorological services on all temporal and spatial scales. There has been major international investment in providing the underpinning science

and operational capacity to deliver climate services (e.g. Vaughan and Dessai 2014; Copernicus 2017).

It is likely that the desire for and availability of such services will increase in the future and will provide many of the future employment opportunities for meteorologists. Therefore, meteorological training needs to reflect both the generic principles of providing a weather and climate service and specific expertise in the most common sectors which use climate services. Specifically, meteorologists will need to understand how to work in interdisciplinary teams that build and use models or chains of models which increasingly incorporate other Earth and human systems. There is a great deal of work, for example in medicine (Nancarrow et al. 2013), which can be built upon to develop teaching materials designed to help students develop the skills needed to succeed in such interdisciplinary teams.

In common with principle 12, meteorologists will also need to be able to effectively communicate to their ultimate end-users how such chains of models are designed and used and what uncertainties and assumptions are included in them.

Principle 9. Meteorological training should prepare meteorologists to be able to appreciate and evaluate the information available through observations and measurements.
The information used in weather and climate research and forecasting comes from measurement systems, such as those used for regular synoptic observations and organised by international treaties, or planned satellite or radar systems implemented at national levels by individual meteorological agencies. Advances in computing technology have vastly expanded the range of atmospheric quantities now commonly available, such as through surface based remote-sensing (e.g. networks of ceilometers and acoustic sounders), dense networks of environmental sensors (e.g. for air pollution monitoring), airport clear air turbulence detection and lightning location systems (Said, 2017). There is a range of different uses of data from these and other systems, which will continue. For example, many meteorologists will need to design their own instruments or deploy measurement systems at short notice for critical situation forecasting, or merely inherit data from distant observation networks (Harrison, 2014).

Training in evaluating the quality of data from a variety of sources is an essential preparation for scientific decision-making, including awareness of the associated limitations. This is particularly important for data the research team did collect themselves, where there is no hands-on awareness of the systems employed and therefore a remote assessment of the capability of the system together with appropriateness of the processing applied will be needed. Furthermore, progression towards many more diverse observations can be expected, as part of internet-facilitated measurement networks. The associated sensors will not be as well maintained as conventional meteorological networks, simply because of the large numbers involved, meaning that the data used will be of variable quality. This further necessitates the need for training in careful evaluation of the measured data and derived data products. Nevertheless, the utility of such inexpensive sensor networks can be substantial, as denser lower quality networks can provide information comparable with that obtained from sparser professional quality networks (Barnard et al, 2016).

Skills in using measurements and instrumentation have traditionally been obtained through a combination of laboratory training and field work, as well as visits to sites where particular instruments and systems are used. In this, laboratory work encourages appreciation of systematic and random errors (which links to Principle 10 on statistical awareness); alternative virtual models for traditional laboratory investigations such the Open University's OpenScience Laboratory (Open University, 2017) could be brought into some aspects of the meteorology curriculum. A particularly efficient cross-cutting meteorological technology for this educationally has been the balloon-carried radiosonde, because of the immersive exposure it brings in generating three-dimensional atmospheric data with a modest amount of field activity, together with the limitations of the sensors carried and the strong link it provides to operational forecasting. Other airborne platforms, such as unmanned aerial vehicles, can provide further opportunities and are likely to carry multiple sensors of different kinds. These point beyond the conventional approach of laboratory familiarisation with instrumentation and data analysis, towards training around instrument-related software development and data logging, and the connectivity of sensors. This further reinforces the motivation for the software development in Principle 7.

Principle 10: Be competent in designing statistical tools and applying statistical thinking to the atmosphere.
Statistical understanding and thinking is critical to all areas of atmospheric sciences, and forms part of the recommended syllabus in both WMO (2015) and the AMS information statement on Bachelor Degrees in Atmospheric Science. However, although the requirements specified in both of these documents provide students with some basic understanding, the requirements are not to the level we believe is necessary for them to succeed as meteorological professionals.

Regardless of the content of individual statistical curricula, an important change to statistical education for atmospheric science would be to adopt the 'statistical thinking' approach of Chance (2002). This encourages students involved in solving a statistical problem to develop mental habits that consider the validity of both the data and statistical approach throughout the process of experimental design, execution and analysis. Adopting this approach would encourage students to see statistics as integral to their understanding and analysis of the atmosphere. It also mirrors the enquiry based learning approaches to curriculum design which have been shown to improve student learning (Deslauriers et al. 2011). Finally, making the statistical reasoning behind analysis of problems explicit is also likely to help students develop their skills in communicating uncertainty to end-users. (principle 12).

Principle 11: Meteorological training should enable meteorologists to ensure that operational standards and quality are maintained within increasingly automatic systems.
Spurred by the recent high-profile advances in artificial intelligence (Knight 2017) there has been a recent renewed interest in the role that automation might play in weather forecasting (e.g. Grover et al. 2015). While it seems unlikely that artificial intelligence will entirely replace our current forecasting infrastructure based on physical models of the Earth system and human interpretation and communication of their results, it is nonetheless likely that they will play an increasing role in the forecasting process. For example, automated

systems might be particularly suited to the continuous combination and calibration of models described by Stephenson et al. (2005) as 'forecast assimilation'.

For the purposes of meteorological training, it is important that current students will have the skills to adequately interact with assistive technologies like artificial intelligence. One particular challenge is the increasing sophistication of connections between measurement systems, forecast models, weather situations and hyper-local conditions (at the individual post-code scale) that artificial intelligence may reveal. It will be impossible for meteorologists to fully diagnose all of the links between complex the different sub-systems used in the operational environment. Instead, meteorologists will have a different but important role in providing checks on the forecasts that are produced and on designing and implementing the operational standards (as defined by the WMO and other regulatory agencies) under which such automated systems operate.

Principle 12: Meteorological training should prepare meteorologists to be able to effectively understand and communicate risk and uncertainty.
The weaknesses of deterministic forecast systems have long been recognised. However, it is only, really, in the last 25 years that enough computational power has been available to run operational ensemble NWP models (Park et al. 2008). Ensemble based forecasting provides a tangible assessment of a hazard and its uncertainty. The resulting risk the end user faces requires a full understanding of the impact that the weather hazard will have on the end user at a point in time based on their vulnerability and exposure (Field et al. 2012; Penn et al. 2016), the decision making processes which the customer goes through and indeed the background and experiences of individuals making decisions based on meteorological information (Kox and Thieken 2017). Similarly, inter-cultural differences surrounding risk literacy and appetite (Hsee and Weber 1999) will be critical to producing a clear and useful forecast, providing students with opportunities to develop their inter-cultural competency are an important part of this principle. The ability to understand the impact of a forecast, then adjust communication to ensure that the hazard and its uncertainty is adequately represented against the vulnerability of a customer at a point in time (Wall et al. 2017) are therefore fundamental skill requirements.

Principle 13: Meteorological training should prepare meteorologists to be clear in expressing their work in the context of contradictory forecasts or interpretations.
Increasingly, meteorologists need to be careful to explain and justify their work to end-users because of the availability of large amounts of complex and sometimes contradictory information (Morss et al. 2015). Although trust in scientists to tell the truth remains high (IPSOS Mori 2016), there can be significant variations in trust across the population and when issues relate to climate change.

End-users increasingly make use of a diverse range of forecasts at different spatial and temporal scales from a large number of different forecast providers (Abraham et al. 2015) with a potential loss of confidence when forecasts are contradictory (Mulder et al. 2017). The need to prepare students with the skills to make compelling and clear arguments, known as argumentation, is recognised in educational literature. As noted by Sharples et al. (2015) teaching practices need to be carefully considered to support students in developing their skills in argumentation. Excellent guidance exists for educators thinking of including the development of reasoning skills as part of their curriculum (e.g. Michaels and O'Connor 2012) which can be adapted for higher education and vocational courses . In particular, if educators can model effective ways to guide and steer scientific discussion in productive and meaningful ways it is likely this mode of teaching can have the joint benefit of enhancing learning and teaching a key professional skill. Enhancing these skills will also help students to learn to communicate across differing levels of technical skill, both to their colleagues and peers and to end-users.

Principle 14: Meteorological training should prepare meteorologists to be able to interpret their work in the context of a changing climate.
As discussed by Leiserowitz (2012), the future of the Earth's climate is a problem linked inextricably to human choice and behaviour. Our ability to attribute changes in the likelihood of extreme events (Stott et al. 2016) or their impacts (Trenberth et al. 2015) to human activity has advanced rapidly in recent years, with very rapid attribution of events now being delivered by the World Weather Attribution project (Climate Central, 2017). Extreme or unusual climate events, on all spatial or temporal scales, are of significant interest to the media and the general public and provide a prism through which much of our science will be viewed in the coming decades.

The dominance of climate change as a reference frame for communication of much of atmospheric science provides significant challenges for education, both because of the challenges of communicating to a range of diverse audiences with sometimes visceral reactions to climate information and the rapidly developing science of event attribution.

How to adapt curricula and teaching to achieve these principles
In this section, we make that case that with changes to teaching practice, training in all of the principles is feasible, beneficial and enjoyable for students and staff of all institutions. In particular, we advocate the increased use of enquiry-based teaching approaches as a means of combining the teaching of the underpinning skills in our blueprint with the teaching of meteorological fundamentals. We expect that a combination of these approaches with lecture and laboratory based teaching would be optimal and effective for most training providers.

Why enquiry-based learning?
Enquiry-based approaches to learning involve students learning through their own, self-directed enquiries or investigations into a problem. The role of the teacher is critical in this approach. The design of the learning intervention must address the learning outcome required but allow enough flexibility in subject and approach to address broader goals such as encouraging personal responsibility, interest and exploration of a problem. Our experience of delivering enquiry-based modules has been that providing students with authentic, meaningful problems, utilising a range of both formal and informal assessments and providing students with bridging activities which allow them to move from the role of consumer to creator of information are particularly important.

This enquiry-based, active learning approach has been shown to be an effective way for students to learn specific subject content and addresses some of the broader skills identified in our blueprint ((Hmelo-Silver et al. 2007; Deslauriers et al. 2011). A current example of the use of this approach is at the University of Reading, where students are encouraged to use the Held and Hou model (1980) of the Hadley cell to develop experiments to understand the role of the seasonal cycle in determining the cell width. While developing their knowledge of atmospheric dynamics, students also get the chance to critically evaluate the original scientific paper (blueprint Principle 5), develop robust and transparent code (blueprint Principle 7) and facilitate the personal development of their colleagues through providing and responding to peer feedback from their colleagues (blueprint Principle 3).

There are *s*ome challenges in implementing enquiry-based learning in meteorology (Edelson et al. 1999), such as student motivation; accessibility of investigation techniques; background knowledge; student experience of the management of long-term activities, and practical and logistical constraints. In the broader context, our experience has also shown that the support provided by a tutor, line manager or mentor is also critical. Their active encouragement and management of progress throughout an enquiry based learning intervention is fundamental to addressing the motivation of the student and ensuring that learning outcomes are met and are actively used after the learning intervention has completed, increasing the depth and benefit of the learning intervention. Unfortunately, the familiarity and comfort of teaching staff with this approach can be a barrier to its more widespread adoption. Since enquiry-based learning is a relatively mature field, a number of approaches have been suggested and tested that can overcome some of these difficulties. Edelson et al. offer a number of useful suggestions that can alleviate some of these problems.

Summary

In this letter, we make a case for a re-imagining of the atmospheric science curriculum for new meteorologists entering our field at undergraduate, graduate and professional levels. In addition to the core understanding of our subject, we argue for a set of underpinning principles which define the professional meteorologist and form part of all the training that students of meteorology receive.

Measured against this blueprint, our own programmes require development to meet the needs of our students, and we strongly suspect the same is true for most other meteorological training providers. Developing our curricula requires the leadership of educators and consultation with employers and students. We think that a move towards greater emphasis of enquiry-based learning in meteorological training would increase the opportunities that students have to develop the skills and attributes discussed in the blueprint. By adopting a common skills curriculum and a shared approach to delivery across all providers of meteorological education and training we hope to be able to produce more effective and robust meteorologists for the 21st century.

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