ACADEMY OF THE SOCIAL SCIENCES IN AUSTRALIA

CLIMATE CHANGE EDUCATION

A summary of research reviews, assessments instruments, and ways forward

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A summary of research reviews, assessment instruments, and ways forward

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http://coolfutures.net/

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I. Introduction

Over just a few decades scientific research has enabled unprecedented advances in our understanding of Earth's climate processes. We are now presented with a clear and reliable view of the changes taking place in our climate, the directions in which those changes could be headed, and the significance and potential consequences of human activities in initiating, escalating, and reversing those changes.

This paper does not set out to rehearse these findings or to reassert the urgency of addressing them. Its impetus comes instead from the observation that developments in societies' knowledge of climate change have not been matched by our efforts to develop, update, co-ordinate, and disseminate educational initiatives in the general domain of climate, environment, and sustainability. This is despite the extensive efforts of a number of educational associations. The time now seems right to marshal the efforts of researchers in support of the efforts of education systems and teachers to align productive policies and practices with advances in knowledge about the nature and significance of changes in our climate.

The research work collected and summarised here on climate-related teaching and learning, and on mapping progressions in that learning, is aimed at improving that alignment. To this end, the Policy Committee of the Academy of the Social Sciences in Australia formed a Climate Change Education Steering Group to examine current research relating to climate change education (CCE). This paper presents the group's summary of its two initial lines of inquiry: 1) What does research say about effective educational interventions aimed at school students and teachers? 2) What ways of assessing such programs have been developed and validated, including the learning progressions that give structure to these assessments?

Our approach to these inquiries is centred on two corpuses of empirical research. The first comprises research compiled by seven recent extensive reviews that have appeared in peer-reviewed journals. These reviews drew together over 350 empirical, largely quantitative and true- or quasi-experimental studies of the effects of a variety of educational interventions focused on CC. The second corpus consists of a selection of 30 recent research reports that detail the processes of development and validation of a variety of assessments, surveys, tests, inventories (henceforth grouped under "instruments"), and models of learning progression.

We describe, summarise, and discuss the outcomes of both inquiries, noting converging and diverging conclusions, in four sections:

i. We draw on the first corpus to outline some general features of the current state of research on effective programs in CCE, including the changing rate of published research over the last decades, the way these research efforts cluster in terms of key concepts and interests, and the various educational settings on which they focus.

ii. The findings from our selection of reviews of effective educational interventions are summarised under five headings: 1) teaching and learning, 2) technologies and learning, 3) teacher education and professional development, 4) policy priorities, and 5) skills- and competency-based approaches.

iii. We summarise a selection of recent research papers that report on the development and validation of instruments to assess CC-related knowledge, skills, practices, and attitudes among school students and teachers. In light of the possibility of the OECD's addressing environmental awareness, concern, and agency in its 2025 round of international student assessment, we include in this section aspects of the relationship between the study of climate and the development of students' reading, writing, and management of multiple forms of representation.

iv. The paper closes with a discussion of the main conclusions to be drawn, some gaps in the research field, and some ways forward for educators and researchers in the area of CCE.

The aspiration here is that summarising key messages from these resources will support the spread and use of valid and reliable developments in curriculum, pedagogy, and assessment, and will also suggest how these three elements might be more practicably co-ordinated, in programs for schools and for teacher pre- and in-service provision, around key ideas concerning the teaching and learning of CC.

II. The state of research in CCE

The last few decades have seen the continuous growth of research on and around CCE. This research has appeared in a variety of outlets, including in new and well-established journals, edited collections, and online sites. Predictably, the conceptual, analytic, and technological resources brought to bear on CCE have expanded, and it has become a field of inquiry that comprises a range of educational settings, methodological approaches, and technical vocabularies. Over a relatively short period of time, research on CCE has become, by any measure, a variegated and complex field, such that the findings we report here are best seen as a sketch of work-in-progress. This section provides an outline of some features of this body of research, as reflected in the extensive reviews examined in the first inquiry.

Most reviewers noted a significant increase in educational attention to CCE, for instance, in the provision of project materials for use by teachers and parents. Aikens and others (2016), however, noted that about 70% of the publications originally collected under the topic search headings were non-empirical, comprising largely reportage of initiatives and discussions of recommendations for CCE.

Along with the increasing development of educational materials, there has been a significant increase in research on CCE. Restricting their scope to empirical studies in CCE that showed some replicability, Monroe and others (2019) located 12 articles published between 1990 and 1999, 433 from 2000 to 2009, and 1489 from 2010 to 2015. Similarly, Aikens and others pointed to an overall significant increase in CCE policy research, with three apparent "spikes" in output in the mid-1970s, the late 1990s, and from 2005-present. These they related to specific, high-profile international announcements or initiatives such as the Decade of Education for Sustainable Development.

Looking in more detail at the research corpus in CCE that we used for our first line of inquiry (a corpus that consists of all scholarly articles cited in the reviews), a further analysis was undertaken to examine patterns of timing, topics, and key terms.[1] Preliminary findings from a hierarchical cluster analysis (Ward, 1963; Cooksey et al., 2007) indicate four interpretable groupings arising from the key terms in a reference list totalling 358 articles. Table 1 shows a collection of the key distinguishing terms (bi-gram and tri-gram tokens) appearing in each of these four clusters. These can be interpreted as indicating the topical content that is distinctive to each cluster.

Table 1: List of tokens in order of predictive content for the four clusters

C1	C2	C3	C4
climate change	global warming	environmental education	sustainable development
change education	greenhouse effect	education EE	higher education
climate change education	ozone layer		
impact climate			
related climate change			
climate science			
effect climate			
effect climate change			

[1] Consultant: Simon Freebody For the full analysis, see Simon Freebody (2021) Literature scan: Climate Change Education. http://coolfutures.net

Table 2 shows the decades in which items in each cluster were published in refereed journal articles, the average number of citations of the most widely cited 10 pieces in each cluster, and the average annual citation rates.

Table 2: Decade of publication and mean citation rates for the four clusters

	Cluster labels	**Decade**	**of**	**publication**			
Cluster number		Before 2000	2000-2009	2010-present	Mean Citation Top 10[1]	Mean Citation per yr	Cluster totals
1	Climate Change	0	5	64	507	13	69
2	Global Warming	9	23	42	357	07	74
3	environmental Ed	17	14	17	179	4	48
4	sustainability Ed	13	73	78	1052	11	164
	Year totals	40	117	201			355

We can note that the research pieces in the Climate Change cluster increase relatively suddenly from about 2010, the Environmental Education cluster entries are proportionately higher prior to 2000, Sustainability shows a proportionately higher-than-expected appearance level 2000-2009, and the research on education relating to global warming reflects the pattern for the overall corpus. Citation rates differ substantially across the clusters, with the most widely cited 10 pieces in the Sustainability cluster massively outnumbering other rates.

Clearly, the headings we combined to produce the corpus of review papers, while semantically related, have evolved distinctive features over time, with consequences for their application to education and their formation of citation groupings. We revisit at several points in the discussion below the issue of the sub-groupings within our general characterisation of CCE.

Reviewers also observed that the overall area of CCE research, including more general "environmental education," had surged since 2009 (e.g., Ardoin et al., 2018; Bhattacharya et al., 2020; and see Lucy et al., 2010). Their explanation was that, as a corpus, CCE research displayed:

- an increasing range of CCE-related concepts and topics;
- a focus on middle-through-secondary years school students (Ardoin et al., 2018, indicated, for instance, that only 8 of the 119 projects in their corpus were conducted with students under the age of 9 years);
- some attention to pre-service primary years teachers; and
- an increasingly complex mix of quantitative and qualitative methods, mostly in the form of surveys, questionnaires, interviews, and observational studies.

Within this setting Bhattacharya and others made the general point that the knowledge, attitudes, and orientations of policy-makers and professional academics tend to be most prevalent in these studies, at the expense of school personnel, classroom practitioners, and members of community groups. This they found to occur especially in relation to policy formation.

A general tendency among these studies has also been noted (e.g., by Salas-Zapata et al., 2018) to investigate topics related to ecosystems, natural resources, and environmental conservation. Salas-Zapata and others also observed that one of the most frequent terms used to relate to CCE – "sustainability" – by policy-makers and curriculum designers, but most notably among teachers and

[2] Citation rates are rounded and refer to the total of references cited in the review corpus.

students, has assumed such a variable set of meanings that its educational use may have become "unfocused." Some implications of this point are developed in sections below.

On matters of theory, methodology, and epistemology the literature reviewed here displays differences and tensions that are longstanding in research on educational practice and policy. These contrasts are, if not taken for granted, at least readily recognisable features of this terrain. Worth previewing at this point, however, is the suggestion that the recency, complexity, and contentiousness that have accompanied the emergence of CCE combine to animate these differences and tensions with a new urgency, and to present a distinctive set of challenges to conventional features of curriculum, assessment, and pedagogy in schools, and, thereby, to current ways of preparing and supporting teachers.

III. The efficacy of CCE: Approaches to teaching and learning

III.1 Introduction

In this section, we collect and summarise a sample of empirical studies, reported over the last 20 years or so, on the teaching and learning of climate-related material. Assembling a manageable corpus of research in this field calls for focus, and we acknowledge that the constraints we have imposed here are effectively judgement calls, and that these delineate, in both obvious and subtle ways, our view of the fields and topics that comprise this domain.

We constructed our search in these ways:

- We limited our attention to effective teaching, learning, and assessment in the school years and in programs that prepared or supported school teachers.
- We focused on the application of quantitative analyses, sometimes in a mix with qualitative methods and design characteristics.
- While acknowledging that these terms are not interchangeable, we included under the general heading of CC some neighbouring concepts such as "sustainability," "global warming," and other terms relating to durable, anthropogenic changes in climatic conditions in air, water, or land.

We began this inquiry by locating recent reviews of research in CCE, followed by an analysis of the author co-citation groupings that relate to the basic search terms (as in, e.g., "education" AND "climate change" OR "global warming"). The aim here was to locate any variations in specialised vocabulary relating to conceptual or methodological groupings not accessed via the original terms. We then searched within those clusters to locate highly cited authors and additional reviews of research.

III.2 Teaching and learning

In this section we draw together reviews of studies that trial, test, or compare various interventions relating to curriculum content and pedagogical strategies. We describe how the reviewers systematised and reported the patterns they detected in those studies: How does the available research answer questions about the efficacy of particular curriculums, project formats, and pedagogical settings and strategies aimed at improving inquiry into CC?

We begin by summarising the conclusions of two foundational, extensive reviews of the published research literature on CCE over the last 2-3 decades: Monroe and others (2019) and Bhattacharya and others (2020).

III.2.1 The review by Monroe and others

Monroe and colleagues systematically reviewed CCE research from the period 1990 to 2015. They interpreted this collection, providing an outline of some recurring themes and issues that provide starting points for much of the discussion that follows here. Monroe and others constructed broad outlines around six themes they saw arising from their final corpus, a corpus of empirical studies, with, as they summarised it, "results that are replicable" (p. 793). This final corpus comprised a total of 49 pieces, 28 of them focused on primary or secondary schools, and 11 on colleges/universities; 26 were conducted in the United States, the remainder across many other nations and jurisdictions; 40 studies were aimed at increases in knowledge, and the remainder at changes in attitude, disposition, and intention to act.

Of the themes Monroe and others developed, two apply beyond CCE or environmental education, describing general features of curriculum and pedagogy that are relevant to most educational settings:

- Effective CCE is enhanced in projects that focus on making CC personally relevant and meaningful to learners.
- The activities or educational interventions that were effective were designed such that they drew learners in at high levels of engagement.

Few would argue with the educational significance of "relevance," "meaningfulness," or "engagement," but it is also clear that the conditions that foster these features relate variously to age levels, curriculum areas, and the characteristics of pedagogy that apply within these contexts. The additional four themes that Monroe and others identified provide some instantiation of these general findings, helping to specify effective pedagogical and/or curricular strategies. In general, these themes are aimed at moving learners beyond the basics of climate science and studies of the environment and more overtly toward potentially complex and contentious issues such as climate change, biodiversity, and sustainability. The following are their more targeted conclusions, with some illustrative examples.

- Teachers' co-ordination of deliberative, structured discussion improves learners' understandings of attitudes to and knowledge of CC (e.g., Mason & Santi, 1998). Students can, however, be initially reluctant to discuss controversial aspects of CC, being inclined at first to explore "safer" related matters that are more likely to afford consensus (as in, e.g., Öhman & Öhman, 2013). Researchers noted that student-teacher discussions in classrooms, from very early grade levels in school, and even in tertiary education settings, are generally directed toward consensus. Some studies showed that overt norms for engaging contentious matters in these settings can allow for orderly and productive forms of disagreement and debate.
- Learning and positive, practicable attitudes are enhanced when students are provided with opportunities to interact with scientists and to experience for themselves the processes used by scientists in complex fields of inquiry. McNeal and colleagues (2014), for instance, found that students' understandings of systems were enhanced as well as their appreciation of "scale": When called on to consider changes that take place on magnitudes unavailable to everyday perception – too fast or slow, too big or small – students were more able to locate these processes appropriately when they had guidance in understanding and explicating the systems involved.
- Programs explicitly designed to uncover and address misconceptions about climate change are effective. For instance, addressing misconceptions via experiments was successful in helping 18-year-old students visualise and articulate faulty reasoning relating to CC over the medium and long terms (Niebert & Gropengiesser, 2013).
- Designing and implementing projects, in either school or community settings, that set out to address some practicable aspect of climate change is effective in engaging students. Stapleton (2015), for instance, reported on high school students' encounters with people who had been affected by climate change via an international exchange project. They showed that collaborating with these people on community projects significantly enhanced students' understandings of CC, their sense of its significance, and their ability to put forward ways in which it might be productively addressed.

Monroe and others (p. 806 ff) also noted the research gaps in pedagogy and curriculum pertaining to CCE. They first emphasised the developmental issue: the need for more research that explores how to deal with learners' interests, motivations, and misconceptions at various ages. Questions that need answers include the variable impacts of climate change on learners of different ages. For instance:

- Will economic impacts engage older students and adults more than, say, concern for native plants and animals?

- Is CC a topic that is too “scary and/or sad” for students in the early school years (as some teachers in Ginsburg and Audley’s (2020) study suggested, and as discussed below)?
- More specifically, is teaching about CC contrary to informal cultural conventions concerning young children, or more formalised stipulations such as the US Developmentally Appropriate Practice (NAEYC) guidelines?

Second, they recommended that research explicitly address the interconnection of policy, economics, and the aspirations of individuals and communities: How should nations address CCE – considering, for instance, the cost-benefit analysis of a carefully developed curriculum? How might such an initiative be presented? Should texts, projects and assessments aim for “the lowest level of agreement or shoot for the greatest vision” (p. 16)?

III.2.2 The review by Bhattacharya and others

One of the key questions for Bhattacharya and others was: How do teachers and students in formal school learning environments conceptualise Earth’s climate and global climate change? They located research confirming a range of highly variable and not always consistent conceptions among teachers and students concerning fundamental issues such as the function and nature of atmospheric gases, the greenhouse effect, and the carbon cycle.

These reviewers nonetheless pointed to research that demonstrated some effective strategies for overcoming the complexities involved in teaching CCE, including, for example:

- using “conceptual and physical models” to support students’ understandings of the greenhouse effect (e.g., Shepardson et al., 2017);
- providing opportunities that help learners with their systems thinking and with their ability to integrate these processes as they move forward in their learning (e.g., Hokayem & Gotwals, 2016; and see Karpudewan et al., 2015, for evidence of the efficacy of this approach with primary school students; and Rousell et al., 2017, for an Australian instance of arts- and literature-based approaches in the middle school years);
- developing students’ disciplinary knowledge about Earth’s climate in the early years of schooling as an effective way of building their understanding of the processes and complexities of climate change, and clarifying their reasoning and argumentation strategies via data-driven, model-based forms of inquiry (e.g., Pallant & Lee, 2015); and
- foregrounding the knowledge, understandings, and attitudinal orientations that teachers and students themselves bring to classroom learning about how Earth’s climate works (e.g., Zangori et al., 2017; Zeidler & Newton, 2017).

Several of these studies, along with some others mentioned later in the present review, employed a form of pedagogy grounded in the “socio-scientific issues” (SSI) framework (see Sadler, 2011, for a general introduction to this approach; McNeill & Vaughn, 2012, for an application to CCE; and Songer & Ibarrola Recalde, 2021, on its implications for the improvement of design and evaluation principles in biodiversity education). SSI-based pedagogies focus students on controversial topics that have a scientific basis but that are also of profound contemporary concern to societies at large. This means that these topics sometimes receive scientific and media coverage that calls into question the relevance, accuracy, and degree of confidence in scientific perspectives. Exponents of the SSI approach in schools draw on disciplines across the physical and social sciences explicitly to address emergent and contentious issues with youngsters. These issues draw attention to considerations that are sociological, psychological, ethical, economic, religious, political, and so on. The explicit, respectful juxtaposition of these perspectives, according to proponents of the SSI approach, is at the core of developing an education in and around the topic of CC. Their preferred strategies include: using real or lifelike scenarios in role plays and debates; constructing representative and diverse communities of practice; capitalising on virtual environments, where possible, via virtual or augmented reality technologies; and using data from mass media in which various positions on CC are circulated and identified.

III.2.3 SSI and related findings

Dawson and Carson (2018) provide an Australian example of the SSI orientation to the area of CC. They worked with an early career science teacher who set out to develop his Year 10 students' argumentation skills in the context of SSI, and who chose CC as the target domain. The setting for the study was a disadvantaged school in which 58% of students were in the bottom socio-educational advantage quartile and only 3% in the top quartile, a high proportion of refugee children were from sub-Saharan Africa, and 59% of students spoke a language other than English at home.

Data included a pre- and post-instruction questionnaire, supplemented by extensive lesson transcripts, classroom observation field notes, teacher and student interview transcripts, and students' work samples. The intervention comprised detailed explication of a sequence of lessons in argumentation, and the central outcome of interest was enhanced argumentation skills in a complex and contentious scientific field.

Dawson and Carson found that the instruction had a moderate positive effect on the quality of written argumentation, and a substantial positive effect on the number and range of strategies and collective opinions and perspectives that students included in their arguments. This latter finding they took to indicate gains in the detailed and respectful awareness of multiple views and understandings. The students themselves indicated that they felt their abilities to construct an argument had improved, and they gave specific examples relating to the features that constitute high-quality argumentation and to the importance of the issue at hand. Dawson and Carson offered a nuanced interpretation of their findings:

> *The students significantly improved their understanding of climate change and the greenhouse effect. In particular, they understood the difference between weather and climate, the role of the greenhouse effect in maintaining life, and types of greenhouse gases. It is not claimed that students' understanding of climate change and the greenhouse effect improved because of the argumentation and SSI lessons. Rather, it appears that these lessons can be included in regular instruction … without jeopardising science understanding. (Dawson & Carson, 2018, pp. 879-880)*

In light of the varied backgrounds of students in this study, these gains are, however carefully interpreted, noteworthy.

The emphases in SSI approaches parallel some lines of work within the tradition of "environmental education." From their "systematic review of research on environmental education's contributions to conservation and environmental quality outcomes," for instance, Ardoin and others (2020) summarised the challenges facing researchers with this orientation in this way:

> *Conducting relevant, high-quality scientific research and sharing the findings with decision-makers is not enough to solve complex environmental and conservation issues (Knight and others, 2019; Lemos and others, 2018). Rather, we need synergistic spaces where research findings are interpreted and applied in on-the-ground contexts in ways that acknowledge and meld with social, political, and economic milieus (Toomey et al., 2017). (Ardoin et al., 2020, p. 108224)*

III.2.4 The settings of CCE

Researchers in the area of CCE have also pursued an interest in the particular value of "outdoor" educational experiences such as field studies. Jeronen and others (2017), for instance, reviewed studies of teaching methods in biology, sustainability, and CC, especially those that addressed outdoor education in primary and secondary schools and in pre-service teacher education. In the 24 articles in peer-reviewed journals that they located, they found that the most common teaching methods and settings studied were classroom-based group work, outdoor fieldwork, teacher presentations, and teacher-led discussions. The least common they found to be in-service learning sessions with teachers, whole-school approaches, and arts-based instruction.

In discussing research that addresses the efficacy of these approaches, Jeronen and others drew conclusions that emphasised the value of inductive teaching methods and that centred on students' authentic engagement with environmental issues through first-hand experience – physically in the environments under study. They also emphasised the relatively under-utilised format of the field trip, arguing that its combination with a problem-based orientation offers distinctive opportunities to connect learning with a commitment to act.

Moving toward more specificity in their considerations of the available research, Jeronen and her colleagues documented the features of each of the pedagogical and curricular settings that seemed to be carrying most of the "explanatory weight." The rankings were, from most to least commonly emphasised:

- students' activity, participation, and interaction;
- observation and research work;
- the explicit fostering of awareness and understanding in teacher-student exchanges;
- time and support for reflection on findings;
- catalysing change for sustainability;
- multi-dimensional and multi-sensory information; and
- the use of information and communication technologies.

To summarise, the studies collected in this section give some specificity to the two general conclusions of Monroe and others on the matters of engagement and motivation. Researchers have examined, and variously argued for the features of settings such as interaction in classrooms (e.g., argumentation), the use of realia and modelling, and the natural world outside the classroom.

III.3 Technology and learning

We have noted above that educational researchers have become increasingly interested in the use of digital technologies, including virtual and augmented reality and "serious gaming" (e.g., Smith et al., 2019). Gerber and others (2021), for instance, in their 'search and select' research review, found over 80 games that addressed climate change issues in educational settings and that employed innovative gaming systems. Researchers are increasingly arguing for the distinctive purchase that these technologies can offer for learning about topics whose more challenging elements are too big or too small for the naked eye, or too slow or too fast in their interactions.

A study by Neset and others (2020) illustrates some aspects of this line of work. These researchers designed and evaluated a "serious game" on climate change and adaptation, aimed at enhancing the knowledge, attitudes, and pluralism of perspective of high school students, educational practitioners, and, unusually in this field, politicians and educational policy-makers. The game structured the players' experiences of the tasks around the Agenda 2030 Goals (see United Nations, 2015, Document A/RES/70/1). Each gamer needed to take these goals into account as he or she set about trying to constrain the impact of, for example, extreme or hazardous climatic events.

The findings showed that the game helped players reflect on the challenges related to making decisions about climate adaptation. Several challenges were also encountered, however, by all categories of learners; these included the complexities of interacting systems, and the collective actions and responsibilities across nations and regions, especially when the natural variability of extreme or hazardous climatic events is taken into account. These challenges point to the "grab" and "immediacy" of many short-term game and other digital formats, but also to the longer-term, more educationally "patient" developments in learners' understandings of how systems and people interact.

As an example, in a series of detailed studies with 270 participants across high school, college, and adult learners from a variety of settings, Markowitz and others (2018) examined the efficacy of immersive digital formats on understandings that take into account layers of complexity on the topic of Earth's oceans. They were interested not only in direct learning gains but also in learners' stated interest in pursuing further learning on CC issues. The measures they employed included learning gain scores, tracking data on movements in the virtual world, observations of classroom teachers, attitudes regarding productive actions, and expressions of inquisitiveness. Further, the interventions themselves varied in duration and content, the common element being the use of immersive and virtual reality technologies to study and act on CC. Their findings were generally positive but showed particular efficacy “in the case of difficult-to-simulate learning elements” (p. 18), and for students with special learning needs. They concluded as follows:

> *Our studies show that people can learn about complex social and environmental issues when information is brought to them in an immersive format. Learning also does not appear to be a momentary artifact, as our longitudinal design suggests that people can retain information about ocean acidification weeks after being in immersive Virtual Reality. (Markowitz et al., 2018, p. 17)*

But Markowitz and colleagues were wary of recommending the application of episodic “techno-fixes” to the forms of learning that call for programmatic curricular and pedagogical coherence: “We currently view immersive VR as a medium to supplement the conventional learning environment, not replace it” (p. 18).

This extensive project is an example of the growing body of research and development work aimed at “bringing climate scientists’ tools into classrooms to improve conceptual understandings” (Bush et al., 2019b, p. 25). Bush and others reported a further example, the application of the National Aeronautics and Space Administration’s (NASA’s) Global Climate Model to high-school and junior college students’ learning about the scientific process of climate modelling (see, e.g., NASA, n.d., Watching Earth’s climate change in the classroom). Students who undertook the program scored significantly higher on pre-to-post measures of details of knowledge. They also displayed substantially more complete conceptual understandings of the issue, based on a range of detailed qualitative indices. In discussing their findings, Bush and others concluded:

> *Improvements that further increase accessibility and ease-of-use of complex models are still needed. Work with such scientific technologies can improve understanding of key climate research processes and commonly misunderstood climate research technologies. In contrast, lectures aided recall of key facts but did not generate the deeper understandings needed to promote productive engagement with anthropogenic global climate change policies. (Bush et al., 2019b, p. 33)*

As the relevant technologies become more refined and more readily adaptable to learning at different age levels, the role of virtual, augmented and other modelling- and argumentation-related technologies and media will become an increasingly productive setting for educational research. Substantial economic commitments would be needed to initiate and sustain growth in this area, but that growth needs to be accompanied by ongoing research into the strengths afforded by each technological approach – specifically, how an innovation can, in Markowitz and others’ words, productively “supplement the conventional learning environment.”

III.4 Teacher education and development

A theme that runs throughout these studies, sometimes in the background or as an afterthought in the explanation of results, is how much teachers know about CC, and how appropriately they apply that knowledge in their pedagogy and in their choice and use of curriculum and assessment materials. As researchers tend to focus their attention on the learners and their engagement with a particular feature of the pedagogy or the materials, the role of the teacher in faithfully maintaining, co-ordinating, and following up may appear to be of secondary interest. This tends to remain the case unless the research produces disappointing or mixed results. In the area of CCE, the systematic development and trialling of up-to-date educational materials and strategies for use by teacher educators in pre-and in-service programs is currently patchy.

It is not surprising then that we find conclusions such as “Teachers feel underprepared in their science content knowledge for teaching CC,” and “Teachers consider instruction about [CC] as a low priority” (e.g., Hestness et al., 2014). Plutzer and others (2016), for instance, quantified the problem by reporting that 31% of middle school science and high school biology teachers in their studies presented their students with overtly contradictory messages regarding the causes of climate change. Pallant and Lee

(2015) further found that both students and teachers in their study not only underestimated the impact of Earth's changing climate, but also equated those features of CC that remain "uncertain" in climate data with the absence of useful information about those features.

But, as Jeronen and colleagues (2017) reported, regular teacher development was not a common focus in their corpus of research studies, having been mentioned in only one article out of the 24 published research papers they summarised. Their suggested explanations included teachers' unfamiliarity with sustainability and CC as curricular and pedagogical settings, and that there are "different types of barriers faced by individual students and teachers in teaching sustainability education" (p. 12). That is, a focus on student engagement or on using apparently useful materials does not transparently show up the various challenges that are faced by the teachers in managing, organising, and assessing a multidisciplinary field such as CC. As we emphasise below, documenting the developmental learning trajectory for both learners and teachers across the full range of learning areas emerges as an historically novel priority in the provision of adequate CCE.

III.5 Policy and priorities for schooling

In a systematic review of the literature on policy relating to CCE, Aikens and others (2016) noted that, in their sample of 215 research reports published over the last 40 years or so, many countries in South and Central America, Eastern Europe, North and West Asia, and North Africa were entirely unrepresented, and most of the countries that did feature in the corpus were represented by a single publication. This highly skewed distribution, they asserted, has implications for:

- how policy in CCE is construed;
- what major lines of debate emerge;
- how CC-related challenges are defined and characterised as amenable to formal, institutionalised education; and
- what counts as a culturally-appropriate solution to those challenges.

One of the more subtle questions arising from this non- or under-representation of CC, as it affects literally billions of people, concerns the most productive levels of policy generation and governance in the communities making up the countries missing from our understanding of the CCE-policy connections. That is, the absent countries represent not only "missing data," but likely explain the almost total lack of attention, across this entire corpus, to local-level policy generation and governance on the matter of schooling generally and its potential relation to community practices when it comes to land, water, and food production practices. Aikens and others offer a blunt conclusion on this matter:

> *Sustainability education cannot be assumed to be universally desirable; even as definitions and practices may be broadening, and wide space given to context-dependent interpretation, colonial histories are impossible to escape. Schooling, including for environment and sustainability, has displaced forms of traditional knowledge and its lines of transmission (Mucunguzi, 1995; Vare, 1998). In some contexts, policy for environmental education has been associated with forms of land conservation, in which Indigenous peoples and other citizens have been displaced and excluded from their land (Bak, 1995; Mucunguzi, 1995). Mucunguzi (1995) describes environmental education as representing a form of colonial education, which has effectively written over more holistic and situated traditional forms of environmental education. (Aikens et al., 2016, pp 17-18)*

While Mbah and others (2021) have argued for the global extension of debate around the climate-relevance of local indigenous knowledge systems, most studies relating policy formation and implementation to CCE continue to display the assumption that preferred programs are centrally developed and administered apparatuses, operating across all levels of training, and across both the broad shape and the detailed categories and progressions within curriculum.

It is self-evident that this assumption may simply not prove optimal in the societies that are un- or under-represented here. But equally ominous and perhaps less evident are the unnecessary limitations this assumption imposes on the educational workings of the countries well represented in these studies.

Several countries access and acknowledge the understandings and practices of only a narrow sample of economic and cultural constituencies. They will thereby have only limited capacity to recruit, develop, and disseminate educational policy norms and routines that might productively apply across different levels of their own educational systems – from national to regional to local.

Also noted in a number of reviews are the policy priorities that can actively compete against initiatives such as CCE. Much of the reportage here concerns competition for teachers' and students' time and energy. Pressures from the press, the government, and elements of the community often focus attention on students' achievement in subject areas traditionally regarded as being the core of schooling, such as mathematics, literacy, and science. These concerns can extend to adequate national performance in international surveys of student achievement. And these, in some instances, are connected to a nation's capacity to market its education systems internationally (e.g., Kennelly et al., 2011), and thereby to the prospects for re-election of political leaders.

Related to the question of "competing" educational policies – policies that can be seen as having the potential to undermine one another – some analysts have noted that national educational mandates focusing on testing and performance de-prioritise CCE, not only via the concentration of time, effort, and public concern, but also "through a reliance on individual attainment and competition, discourag[ing] an ethic of environmental and social care" (Aikens et al., 2016, p. 15). In commenting on initiatives in the UK around the CC cross-curriculum area, Huckle (2008), for instance, concluded that there seemed no realistic prospect that such initiatives would be able to "go beyond the ecological modernisation of the school and its community to reveal and challenge those interests and policies that render it difficult to make them truly sustainable" (Huckle, 2008, p. 72).

In summary, there is a crucial issue around those demographics (national, regional, socio-economic, cultural, ethnic, etc) that have been un- and under-represented in the research on policy development and implementation, particularly in a regionally and economically sensitised domain such as CCE. This is an important empirical as well as ideological matter: These imbalances not only influence the efficacy of policy; they also limit the richness of data and educational ideas available to researchers in their efforts to imagine, develop, and assess future policy options.

Further, a question arises as to the nature of CCE as an "educational object." It is clearly a domain of inquiry that has unique implications for the understandings and actions of learners. It presents some substantial challenges to the organisational features of conventional schooling. This was recognised in Monroe and others' conclusions from their review of CCE:

> *The challenges of climate change education suggest that the type of education we have always done may not be sufficient to engage learners in … how they think and question the justification for their ideas. (Monroe et al., 2019, p. 805)*

Over four decades earlier, a similar conclusion was reached at the UNESCO workshop on environmental education in Belgrade, as articulated in the "charter" from that workshop: "Governments and policy-makers can order changes … but all of these are no more than short-term solutions unless the youth of the world receives a new kind of education" (UNESCO, The Belgrade Charter, 1975, p. 2). The implications for policy range from jurisdictional to the local school level, and clearly involve more than the production and assessment of new forms of knowledge across the curriculum learning areas.

III.6 Skills- and competencies-based approaches to CCE

One conceptual thread that runs through some sections of this corpus of research comes under the heading of skills- and/or competency-based approaches. While there is debate about the terminology, the term "skills" suggests more specificity, and is taken to refer to effectiveness in the completion of a circumscribed task. "Competency" usually refers to a more general set of co-ordinated knowledge and practices that affords effective management in a domain of activity, such as a work or a learning site. The argument is that these approaches can be useful in building bridges between, for example, learning about CCE as a distinctive, complex, and changing area, and the range of institutionalised curriculum domains that are potentially relevant to the study of CC. They may provide a higher level of generalisation than a task, but be nonetheless discrete enough to allow translation into different disciplinary domains and pedagogical approaches.

Even though it is over a decade old, the most detailed and comprehensive review of approaches to specifying the "key competencies" involved in teaching and learning about CC is provided by Wiek and others (2011). They compiled and analysed in detail the available literature up to 2010 on the topic of students' competencies for sustainability. One aim was to assemble "the key competencies that distinguish the sustainability field from other academic fields and that are critical for students to acquire" (p. 211).

Wiek and his colleagues used this definition of "competencies":

> *A functionally linked complex of knowledge, skills, and attitudes that enable successful task performance and problem solving (cf. Spady 1994; Baartman et al. 2007). Applied to competencies in sustainability, these are complexes of knowledge, skills, and attitudes that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges, and opportunities (cf. Dale and Newman 2005; Rowe 2007; Barth et al. 2007). (Wiek et al., 2011, p. 204)*

They listed these as most pertinent to the study of sustainability:

- systems thinking (e.g., definition and justification of elements, components, and dynamics);
- anticipatory competence (e.g., fore- and back-casting methods and models, shaping pathways);
- normative competence (e.g., mapping, specifying, applying, reconciling, and negotiating values and principles);
- strategic competencies (e.g., designing and implementing transitions); and
- interpersonal competencies (e.g., motivating, enabling, collaborating, etc.).

They argued that a field such as CCE calls not only for distinctive inflections of each competency, but also for their distinctive combinations. Wiek and others observed that examining the evolution of these processes can help the field of sustainability mature as a program in its own educational space, and thereby beyond its "anchors" in a variety of existing institutionalised discipline formations (p. 203). This may imply the eventual establishment of this subject as a separate learning area, but it also points to benefits in detailing the ways in which the area can connect across the curriculum domains, as it is currently required to do in several jurisdictional and national curriculum formations, including in Australia.

In related work Salas-Zapata and others (2018) reviewed competency-related research in the area of CCE from 1990-2016. They used a framework involving knowledge, attitudes, and practices to collect studies that evaluated sustainability activities in different demographic groups and in various educational settings. Among their complaints about what they found in the corpus they collected (p. 56 ff) were these:

- students' and teachers' knowledge of sustainability was limited, often out of date, and not theoretically coherent (e.g., Burmeister & Eilks, 2013; Munoz et al., 2009);
- attitudes related to sustainability, such as motivation, satisfaction, and disposition towards solidarity, social responsibility, and equity, were rarely emphasised; and
- practices such as cooperation and reciprocity were rarely dealt with (e.g., Ostrom, 2011).

While they found numerous studies focusing on the development of learners' knowledge of sustainability, and some cases of attention to practices, Salas-Zapata and colleagues' main observation concerned, effectively, the absence in CCE research of attention to attitudes and values:

> *… a concern for the distribution of benefits and externalisation of the costs of human activities, responsible behaviour towards others and cooperation to resolve collective problems, were not a focus of interest in these studies. (Salas-Zapata et al., 2018, p. 57)*

The competencies that teachers need in order to engage students in learning about sustainability have also been addressed by Corres and others (2020). Of particular interest to these researchers were those competencies with the potential to promote what they termed "transformational" perspectives – "transformative learning entails conscious changes in attitudes, values and behaviors … makes the consciousness evolve into 'seeing things differently' (the epistemic dimension)" (Corres et al., 2020, pp. 20-21). They were keen to find evidence for those pedagogical strategies that might develop these perspectives.

Corres and others found that the four most common competences evident in their corpus were, in order of frequency: critical thinking, making connections, participation in community, and tolerance. Less often addressed were learning opportunities that afforded trans-disciplinarity, emotional management, innovation and creativity, and transformation. Their strongest recommendations concerned the competency of transformation, which, they argued, calls for combinations of all the others, in the sense of a "meta-competency" – the competency that affords and sustains the others.

In this respect, these researchers revisited the multi-faceted nature of sustainability education in ways comparable to the model of Salas-Zapata and others (2018), as discussed above. The implication behind several of their conclusions is that "sustainability," as an educational object at least, is commensurate with an informed and collaborative action brought to bear on the "re-thinking" of environment and of humanity's place in it, rather than a body of knowledge that sits beside other curriculum formations.

IV CCE: Assessing CC learning

IV.1 Introduction

One conclusion drawn from the reviews summarised in Section III is that more attention needs to be paid to specifying the outcomes of CCE programs. In this section, we focus on the ways in which educational researchers have developed and validated ways of assessing actual and desirable outcomes relating to CCE.

We set out to collect and interpret a sample of widely-cited, recent, peer-reviewed research papers that focus on the development and validation of "instruments" – a general term we henceforth use to refer to assessments, inventories, scales, surveys, and so on. We examined this sample of research papers to address these questions:

- What have been advanced as valid and practicable learning goals and outcomes in CCE for school students and for pre- and in-service school teachers?
- How are these operationalised in instruments and in learning progressions?
- What general topics and sub-elements (tasks, domains, dispositions, etc.) have characterised the contents of these instruments?

We follow this summary of instruments with a discussion of how to formulate learning progressions, and we conclude with some implications of our findings for both teacher development and classroom learning across the school years in the area of CCE.

IV.2 Constructing the research corpus

In compiling the search terms[iii] for the initial corpus of instruments, we took account of the target populations of the studies, the various forms of nomenclature in the fields collected under the terms relating to CCE, and the forms of research that we expected would form the setting for the development and validation of an instrument (developing tests, surveys, program evaluations, etc.). The search criteria for this initial corpus were aimed at collecting studies that focused on detailing an instrument's development and validation alone, or that worked that instrument up as a part of documenting the features of an educational setting – assessing an intervention, exploring demographic differences among respondents, and so on.

We refined that search to construct an "interim" corpus by submitting the initial corpus (of about 770 studies) to a simple text-based cluster analysis. This process yielded three clusters that showed distinct and interpretable characteristics. We excluded studies that applied an instrument as a component of a project without including any detailed description of that instrument's development, reliability, or validity.

We further sorted research publications based on their citation rates in light of their recency: Papers published from about 5-20 years ago were sorted by mean citation rates per year; more recent pieces were sorted based on educational climate initiatives from otherwise largely under-represented geographical areas. The aim here was to avoid concentration around a narrow geographical region. The top 10 papers by citation per year were taken for each cluster, while every eligible paper published since 2018 was individually examined and reviewed. This process, which produced the "final" corpus, allowed for the exclusion of papers that did not meet some aspects of the requirements. Generally, these exclusions related to the quality of the development and validation processes or the completeness of their description.

IV.3 Findings

In this section, we interpret our findings from this final corpus of research and development on the assessment of teaching and learning relating to CC. Taking note of the characteristic features of each cluster, we distil the findings from the final corpus under three headings: 1) climate knowledge, 2) climate orientations, and 3) the climate curriculum.

As noted above, the cluster analysis of eligible papers yielded three interpretable groupings. Key features of these clusters and an index of the relevant research papers are summarised in Table 3.

Table 3: Target groups, key terms, countries represented, and reference index for the three-cluster solution, final corpus

	Cluster 1	**Cluster 2**	**Cluster 3**
Target group	Teachers (5) Students (3) Both (2)	Teachers (pre- + in-service) (8) Students (2)	All teachers (pre- + in-service)
Key terms	* Climate * Climate change * Climate literacy * Global climate change	* Environmental: • education • problems • attitudes • practices * Literacy * Biodiversity and climate change	* Environmental: • citizenship • education • literacy • sustainability * Socio-scientific approaches
Countries represented	Australia, France, Italy, Malaysia, Netherlands, Norway, Sth. Africa, Spain, Turkey, USA	Brazil, France, Germany, Serbia, Sth. Korea, Spain, Turkey	Australia, Cyprus, Finland, Germany, Israel, Japan, Jordan, Palestine, USA
Index in references	1, 4, 5, 6, 7, 8, 11, 12, 13, 14	2, 3, 9, 15, 16, 19, 20, 21, 25, 29	10, 17, 18, 22, 23, 24, 26, 27, 28, 30

A number of items from Table 3 are noteworthy:

- There is remarkably little crossover in the use of the key terms "climate," "environment," and "sustainability." Clearly, Cluster 1 represents studies concerning climate, climate change, and climate literacy; Cluster 2 is entirely populated by studies of environmental issues and the relevance of these to literacy and biodiversity; and Cluster 3 represents a slightly different take on the emphases within the field of environmental studies, in particular, the contested nature of CC, and the more overt consideration of the implications of climate-related issues for citizenship in contemporary societies.

- Twenty countries are represented in this corpus. It is a broadly-based body of work that is by no means dominated by contributions from Europe or the Anglosphere. But still, large countries such as Russia and China are not represented, nor, apart from Norway and Finland, are countries in the polar zones.
- Most of the attention in the research reports comprising the final corpus is directed at documenting the knowledge and understandings of pre- and in-service teachers. This is probably because of the ready availability of this group in substantial numbers to university and college researchers. It might also reflect one of the central findings from our review of the efficacy of various approaches to climate studies – that the education of teachers is a precondition of productive learning in schools.

IV.4 Aspects of climate studies

IV.4.1 Introducing the KSPA framework

[1, 4, 9, 10, 11, 12, 17, 22, 25, 26, 27, 28, 30]

Terms relating to CCE used in this corpus amount to a complex set of learning goals, calling up:

- a distinctive body of knowledge,
- epistemic skills and practices, and
- a set of affective responses, often seen as
- attached to normative, ethical, and moral stances, in turn, directed at
- a variety of individual, community, social, and policy actions.

As educational objects, the terms relating to "climate," "environmental studies," and "sustainability" are used variously, at least in this corpus, to refer to this collection of aspects.

While the labels and the relative emphases across the corpus vary, the combination of organisational concepts – in this case, knowledge, skills (incorporating competencies), practices, and attitudes – provides an adequate and representative organisational framework for this discussion. The framework provided in Worsley and Skrzypiec ([30], 1998) is comparable, and we give some detail to it here to contextualise the more schematic representations of the work we summarise in other parts of this section. Worsley and Skrzypiec examined the "environmental attitudes" of about a thousand senior high school students, average age about 16 years, from 32 schools in Australia. The 40-item questionnaire they developed inquired into these areas:

- knowledge about environmental systems and processes, the scale and impact of environmental threats, the natural and human causes, and possible social, political, and technological solutions;
- behaviour, in terms of intention to act, orientation to participation, belief in the possibility and efficacy of collaboration and activism;
- affect, on a broad continuum from hope to pessimism; and
- attitude, including norms (e.g., responsibility, collaboration, anthropocentrism, anthro-exemptionalism), and beliefs (e.g., limits to growth, the eco-crisis).

Worsley and Skrzypiec's analyses of the students' responses produced seven interpretable principal components, accounting for about half of the total variability. These factors, in order of their statistical significance, they labelled "environmental concern, environmental pessimism, environmental exploitation, science solutions, environmental optimism, environmental protection, and technological solutions." Significant gender differences were found in favour of males on the belief that scientific and technological solutions to environmental challenges will be found, and in favour of females on general levels of environmental concern.

We expand on this example as an early acknowledgement of the useful separation of knowledge/skills, practice, and attitude/affect. Most of the 30 research studies comprising the final corpus deploy some version of this framework, or at least some of its major features. Our use of it here builds on two features commonly found in the corpus: the separation of knowledge and skills, and the folding of affective considerations into a larger category that includes attitudes, beliefs, and emotional, normative, value, and ethical orientations (Lombardi & Sinatra, 2013). The final organisational model, the "KSPA framework," is represented in Table 4.

Table 4: "KSPA framework" and features of each domain

Domain	Features
Knowledge	epistemic, conceptual, empirical, and social aspects
Skills	cognitive and social capabilities
Practice	intended actions, behaviours, and solutions
Attitude	attitudes, beliefs, and normative/value/ethical orientations

The usual cautions apply when a complex, decades-long tradition of study and application is compacted into a neat schema. Important nuances can be lost in the interplay across the domains and among the features. This applies particularly when the goal is to apply an instrument to educational settings. For example, students and teachers are person-categories not usually populated by experienced, specialist practitioners in the areas of climate/environment/sustainability. Further, both students and teachers are seen to be responsible for working within an externally mandated set of contents and goals. The curricular history of CCE being relatively short, the distinctions among the domains and features in Table 4 are less clearly articulated than in other curriculum areas, as are the implications of those distinctions for pedagogy and assessment.

Similarly, while the groups that work with the vocabularies of "climate," "environment," or "sustainability" address many common topics, with some slight variations in terminology, those variations may nonetheless signal substantial differences of emphasis – reliance on differing research traditions, as well as differing degrees of attachment to the scientific versus the educational community. We now summarise our findings in terms of the KSPA framework, and, in a later section, we revisit some of the concerns and implications arising from these cautions.

IV.4.2 Knowledge

(epistemic, conceptual, empirical)

What are the fields and topics to be "known about" in the study of climate in schools, according to the development of instruments collected in this corpus? Table 5 presents a summary of our findings in this regard.

Table 5: Collection of general, central, and indicative topics by field
[1, 3, 5, 11, 12, 14]

Topics		General	Central	Indicative
Fields				
* processes * causes * impacts * solutions		* weather vs climate * nature of CC * Earth's climate systems * carbon cycle	* greenhouse effect * natural vs anthropogenic drivers * causes of CC * carbon cycle and fossil fuels * interactions between GH gases and radiation * radiative forcing capacity	* consequences of CC * natural climate variability in the past * relationship to CO_2 levels * biodiversity, (incl. extent of, and changing distribution of species) * global CO_2 emissions and future climates * global warming * ozone layer depletion * sea level rise * proportions of GH to non-GH gases in atmosphere

In common use are variations on the schema presented in Table 5: Notably, some researchers, (see, e.g., Duschl, 2008; Duschl et al., 2011) have suggested four types of specifically problem-oriented knowledge (as in [21]):

- situational (knowledge about domain-specific situations; e.g., extracting relevant information from a problem description and adding further information);
- conceptual ("concepts, facts and principles that apply within a certain domain," allowing the problem solver to change the state of the problem);
- procedural (actions that are suitable to certain types of problems in the specific domain); and
- strategic (the sequential action steps necessary to solve a problem).

This re-inflected knowledge taxonomy aims to take directly into account the observation that this area comprises not only scientific, conceptual understandings about known findings and their explanations, but also knowledge about actions, and about the efficacy of those courses of action that attempt to respond to the problem at hand (e.g., [9] includes natural history and ecology, environmental problems, and socio-political-economic factors as elements of knowledge about climate, and see Harraway et al., 2012). It thereby aims to point to some productive crossovers among the elements of the framework, in this case with Practice and Attitude, whereby the term "solution" relates to a topic of inquiry, as well as to an intention to practice, as well as to a norm or disposition.

IV.4.3 Skills

(teachers' and learners' cognitive and social capabilities)
[9, 23, 24, 26]

Most research reports in this corpus make some reference to the importance of assessing learners' skills, especially those attributes and competencies that learners need in order to come to terms with complex fields such as Earth's climate. In this corpus [9, 10, 24, 26] these skills include:

- identifying the issue or problem;
- collecting the information;
- analysing the information;
- gauging the information based on evidence;
- evaluating the information based on personal/social values; and
- synthesising conclusions.

It is arguable that this collection represents a generic set of skills that could form part of many school and domestic settings, even in simple tasks that young children might be called on to complete. When these elements, however, relate to students' and teachers' abilities to talk, model, read, and write about climate – their analyses, their collecting and evaluating of evidence, their syntheses and conclusions, and the rest – the standards applied to them become more specific, and their interplay more complex. Adding to the challenges for students and teachers across the various curriculum domains, those skills need to be enacted within the context of the specific curricular/disciplinary area at hand.

We can note here the "hidden" aspects of learning modalities in the specific case of climate: Physical and social scientists working on climate describe, document, analyse, model, and explain aspects of the climate and the consequences of its changing nature, all using a range of mixed modalities and communication technologies. In the "Summary for Policymakers" of the Intergovernmental Panel on Climate Change (IPCC), Assessment Report 6 (2021) for example, the 41 pages of writing in the Summary present a total of 34 graphic and iconic representations. These interact in a variety of ways with the accompanying written text. That is, the meanings drawn from each modality do not simply replicate or exemplify those drawn from the other; they contextualise and extend one another (Yu et al., 2020).

The integration of linguistic with non-linguistic symbols has been foundational to the development of understanding of central aspects of climate processes, causes, impacts, and solutions. This multi-modal literacy characterises a wide range of educational materials available for mid-high school use in CCE, and any genuine consideration of content, pedagogy, and assessment of climate learning will take multimodality seriously, along with its emerging affordances in digital settings.

An extensive three-round Delphi study conducted to frame an instrument for educators ([24] Seo et al., 2020) led to the following final model of "domains" and "competences" indicators for the course "Environment" in a wide collection of secondary school curriculums.

Table 6: Domains, skills, and abilities [9, 10, 23, 24, 26]

Domains	Skills	Abilities
intellect-oriented	* identify the problem * collect the information * analyse the information * gauge the information based on evidence * autonomy	* problem-solving ability * critical-thinking ability * conflict
personality-oriented	* evaluate the information based on personal/social value	* ability to reflect * environmental sensitivity * autonom
relationship- oriented	* communicate conclusions and rationale	* communication ability * ability to manage contestation and conflic

The expanded version of the "skills" issue shown in Table 6 places more explicit emphasis on the embeddedness of cognitive and linguistic skills, on the contested nature of many social settings, and on topics within CCE in schools and other institutional settings such as teacher preparation in universities and colleges.

As each curriculum area draws on the discipline to which it relates, it provides these otherwise abstract, generic competencies with their own distinctive instantiations. A 15-year-old school student, for example, in many cases having experienced nine or more years of schooling, needs to read and construct texts that are part of the learning process, that is, that model the cognitive and linguistic features of what counts as "critical thinking," "reflecting," "communicating," and the rest – specifically for the curriculum area at hand. We develop this issue further in the section below on learning progressions in CCE.

IV.4.4 Practices

(the effective actor, the bases for acting, intention to act)
[1, 6, 7, 13, 21, 23, 30]

Much of the research appearing in this corpus has included aspects of behaviour and practice – real, intended, and projected – as an important component of CCE. These we group under the heading of "practices," a term that combines elements concerned with disposition (e.g., an orientation to solutions, a sense of personal efficacy), with cognitive and linguistic skills (e.g., collecting and weighing up relevant data, understanding the plausible range of actions and their unintended outcomes), along with a reflection on personal norms and values.

So, at least in this corpus, we find that an orientation to solution is variously described as an element of both "practice" and "attitude." Its conceptual "core" is sometimes characterised as a reasoning practice (e.g., [23]), sometimes as a type of strategy-directed knowledge (e.g., [21]), and sometimes as explicitly attached to the role of science in sustaining optimism and productive action (e.g., [30]).

Figure 1 is an attempt to co-ordinate the various contributions from the corpus to the elements and contexts of Practice. It notes the centrality of exploration of the field, development of a rationale, and willingness to revise and persist. These are taken to be elements related to personological variables to do with efficacy and the ongoing emotional maintenance of a willingness to act [6, 7, 13]. The corpus thus points to these elements as having theoretical coherence within a larger framework for climate studies, as well as to empirical support from the development and validation of instruments.

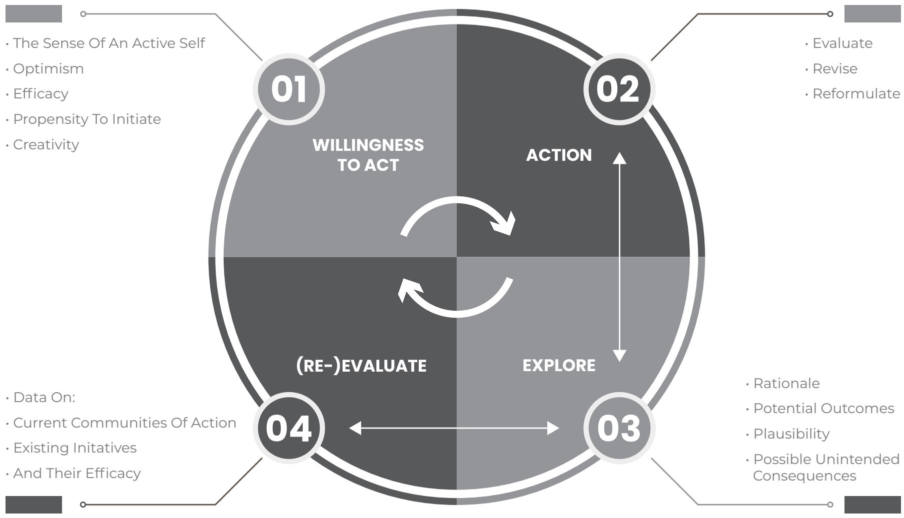

Figure 1: Integration of approaches to the Practice element of the framework, as found in the final corpus (most directly from [6, 7, 13])

What does the Skills aspect of the KSPA framework suggest should be assessed in learning about CC? Possible examples include assessing students' and teachers':

- understandings of how and how well the conduct of CCE is viewed as practical activity, as a way of drawing out possible implications from the combination of knowledge and disposition;
- creativity, coherence, and planfulness in connecting implications for practice;
- exploration of how current initiatives – individual, community, political, industrial/economic – might predict the consequences of a particular practice, and develop the productive revision and reformulation of a practice;
- explicitness, detail, and rigour in revising and reformulating their work; and
- management and regulation of their emotional responses to the topics at hand.

IV.4.5 Climate orientation

Attitudes (disposition, affect, beliefs, norms/values/ethics)
[4, 6, 7, 13, 16, 20, 22, 30]

Commonly found in Clusters 2 and 3, in which most researchers used the vocabulary of environmental studies and sustainability, were both teachers' and students' attitudes, broadly construed, as key interests. The insufficiency of a knowledge of the physical science of CC alone in shaping intentions or behaviour was a conclusion commonly observed in our review of the efficacy of efforts in CCE. Educators, particularly those working in the social sciences and humanities, along with teacher educators, often emphasised the need for some direct attention to normative orientations and to the importance of positive affect among learners on matters such as climate crisis.

A summary of elements addressed in the research on the general issue of attitude in CCE assessment instruments is provided in Table 7. As before, such a summarising exercise calls for judicious interpretation. Clearly, some of these orientations have connections across the columns, and some point directly to the domains of Knowledge or Practice as well as to Attitudes. This attempt to systematise contributions to the corpus that emphasise these features is partly aimed at reflecting the empirical work summarised here; it also tries to produce some coherent collection of potentially assessable, but often unremarked aspects of CC.[iv]

Table 7: Disposition, affect, beliefs, and norms

Disposition [4]	**Affect [4, 13, 16, 17]**	**Beliefs [13,16,20]**	**Norms [13, 16, 22, 30]**
* Optimism * Self-efficacy * Willingness to act	* Sensitivity to climate * Affection for nature * Sense of fragility of nature's balance	* Limits to growth * Capacity of humans to upset and support the balance of nature * The efficacy of collaboration and climate activism * Intergenerational justice	* Sense of responsibility * Ecocentrism * The rights of nature * Anti anthropocentrism * Anti-human-exemptionalism

What does the Attitude aspect of the KSPA framework suggest for the assessment of CCE? Possible examples include assessing students' and teachers':

- views of the prospects for a climate-positive future;
- grounds for making that assessment;
- understandings of the term "nature";
- emotional attachment to nature;
- perception of humans as separate from, or in, or as nature;
- sense of the robustness or vulnerability of nature to human activity;
- sense of the efficacy of small- and large-scale human projects aimed at climate support;
- sense of the efficacy of local- and national-level action for climate support; and
- estimation of the relative responsibilities of individuals, communities, industries and businesses, and nations.

IV.4.6 The climate of curriculum

(CCE as institutionalised programs for students and teachers)
[2, 3, 8, 15, 17, 18, 19]

Students and teachers have figured in all the accounts above of the teaching and learning about CC. Those accounts, however, have not for the most part been framed by a direct recognition of the institutional aspects of teaching and learning in schools: the formalities of institutionalised content, pedagogy, and assessment; the transformation of fluid, evolving knowledge into curriculum; and the kinds of sorting, sifting, and selecting processes that those formalities are partly designed to effect and rationalise.

Some historians of knowledge and curriculum have shown how disciplines and their gradual institutionalisation as curriculum domains have afforded a productive interaction between constraint and creativity. As Anderson and Valente put it: "The term 'discipline' captures the sense of a dual mandate, carrying a sense of practical regimen into an economy of conceptual enterprise" (2002, p. 4), a form of regulated agency, allowing the inter-generational transfer of the defensible connections between knowledge and innovation.

In most school systems, access to increasingly specialised knowledge and discourse emerges with more stringency as the school years progress. As we noted earlier, an ecologically valid approach to assessing the climate-related knowledge, attitudes, and practices of, for example, 15-year-old school students would necessarily take into account the reasonably, but not fully developed epistemic and linguistic concepts and language that are taken to characterise that stage of schooling. Such assessment would need to be built on an empirically supportable "map" of these developing processes of specialisation.

Summarised in Table 8 are research reports that overtly relate to the institutional roles of students and teachers, the ways in which live, contentious, and rapidly evolving bodies of knowledge, constraint and agency, are shaped by the institutional features of schooling – the skills, practices, and attitudes that sustain the organised operations of schooling.

Table 8: Schooling – the topics, demands on students and teachers, and institutional formations of climate studies

Topics of CCE (EE, CC, Sustainability) [2, 3]	**Students' KSPAs for learning CCE [8]**	**Teachers' KSPAs for teaching CCE [15, 17, 18, 19]**	**Institutional forms of CCE [18, 19]**
* global warming * greenhouse effect * ozone layer depletion * acid rain * pollution * biodiversity * natural spaces * recycling	* knowledge and views of: • the authority of science • scientists • school science • societal implications of science climate change • just for school? * a career interest in science?	* subject matter * educational goals * learners' state-of-knowledge and attitudes * instructional strategies * evaluation processes * local environmental context * environmental pedagogical content knowledge * multi-modal/digital representations	* curriculum * certainty and probabilistic thinking * direct experience-based learning * teacher dependence/ compliance * explication of cross-curriculum outcomes * curricular representation of Attitudes domain (management of dispreferred responses in classrooms)

This characterisation of the forms in the KSPA framework draws our attention to a recognition that co-ordinating, in explicit, visibly reasonable and fair ways, the content, pedagogy, and assessment of a contentious, loosely structured field of knowledge puts pressure on students and teachers. In that light, possible assessment outcomes should include students' and pre- and in-service teachers':

- understandings of the teach-ability and assess-ability of the key topics of CCE;
- descriptions of the ways in which their own specialty, and those of their colleagues who teach in other curriculum areas, uniquely inform the epistemics, topics and functions of CCE – what elements and combinations of the KSPA framework do they count as "climate literacy" in each curriculum area?
- more specifically, understandings of the educational status of probabilistic thinking and its relationship to certainty, in the practical setting of the classroom, and considering the practical demands of assessment and grading;
- understandings of how matters characterised by potentially intense disagreement or uncertainty might be resolved in the classroom for the practical purposes of advancing learning, and of providing useful assessment – What forms might such resolutions take?
- awareness of emotional responses and sense of agency about the future.

IV.5 Discussion: Assessing CC

The United States Global Change Research Program (2009), in a joint statement with the American Association for the Advancement of Science, has defined the "climate-literate person" as someone who

> *understands the essential principles of Earth's climate system, knows how to assess scientifically credible information about climate, communicates about climate and climate change in a meaningful way and is able to make informed and responsible decisions with regard to actions that may affect climate. (p. 4)*

This is a definition that is both ambitious and specific, especially when its implications for education are considered. The goal is that members of a society be empowered to gather and evaluate information about climate change and related topics, such that they can make informed and practicable decisions (Mittenzwei et al., 2019).

The specification "climate" as it attaches to the "literate person" raises issues about the relationship of studying "climate" to the goals of schooling. It is clear from research summarised below that these goals should no longer be considered generic: The various curriculum domains conventionally encountered by high school students are in the business of putting intellectual, socio-cultural, and technological processes to work for their own distinctive purposes. A considerable body of research draws our attention to the contrasting cognitive and linguistic demands that these domains present to students. But "climate" is not generally a curriculum domain; indeed, it can be regarded as spanning a range of curricular formations, and in many educational jurisdictions it is regarded as more appropriately a topic for multi-disciplinary inquiry.

A second set of challenges concerns the uneven acceptance of the significance of climate change, climate crisis, climate citizenship, and so on. While high levels of consensus support most of the central claims made by climate scientists (summarised e.g., in IPCC, AR6, 2021), there remain areas of contention over general and specific aspects of climate change. Individuals, communities, and governments differ on fundamental matters such as the extent and imminence of threats posed by climate change, and the degree of responsibility for the problems and for their resolution that should be borne by individuals, communities, and nations in differing locales and socio-economic conditions.

These issues all bear on ideas about what role education systems can and should play in addressing climate-related issues. The socio-scientific approach to climate change education (e.g., Sadler et al., 2007) represents an attempt to deal with this context of contention-at-all-points in the classroom. Schools are settings that, at first glance, are not well-designed for the public exchange of potentially adversarial views. Are classrooms locations in which participants are used to engaging in such exchanges, or to reading, writing, and discussing texts that display and navigate a contested field? Being able to understand and communicate effectively on the topic of climate, as that topic appears in public discourse, necessarily entails managing contention. So the ways in which school students might productively interpret and represent that contention in texts needs to be one component of assessment, and the pedagogical forms that support it. This raises a question for every level of a youngster's education in CC for schools and for university: "What counts as an educationally adequate reaction to knowledge-amid-contention?" (Shephard et al., 2015).

As a topic of educational assessment, CC presents three questions on this front: Is knowing and reflecting on the omni-relevance of different opinions part of CCE? When? In high school? What can count as the educationally adequate management of strongly held competing views about CC? How might we document students' progress in their understanding and navigation of these contingencies?

IV.5.1 To "progress" in knowledge, skills, practices, and attitudes about CC

The term "curriculum" derives from running "a course," negotiating tasks in a given order. Most school systems are predicated on age-based gradations in learning. These gradations are attached to a wide range of student attributes, such that a Grade 4 student may be described as "not reading at a Grade 4 level." While educators are keenly aware of individual and socio-demographic variations in the pace and sequencing of their students' learning progress, a staged progression through a learning area is one of the organisational mainstays of contemporary school systems. Approaches to differentiated teaching and learning, however important they may be to individual students, are largely fine-tuning within that institutional foundation.

Any attempt to position a valid assessment at a given point in learners' trajectory, therefore, necessarily reflects important assumptions about what those learners have accomplished before that point to make its appearance possible, and how the current learning is itself intended to support their move to the next point. For our purposes, how do we characterise the learning outcomes – processes and topics – that have formed the learning trajectory to this point? And from what roadmap can we draw inferences about what will follow?

We can ask: What counts as "forward movement" in teaching and learning about CC across the school years? Any answer needs to be built on an understanding of the observed progressions in cognitive and linguistic development more generally across the school years. In this section, we briefly mention three of the ways in which this issue has been addressed:

- as a matter of scale, complexity, and observability of objects and processes;
- as the engagement of curriculum areas on a continuum from pre-curricular to inter-curriculum understandings; and
- as a linguistic "roadmap."

Roadmap #1: "Rescaling" objects and processes

One way of characterising the challenges faced in learning about CC focuses on the objects, phenomena, patterns, and processes to be studied. Most disciplines of study, as they develop in their technical capacities, discover, or, where necessary, invent objects of inquiry that are not readily available to the human senses. These phenomena may be too big or too small, too fast or too slow, too imminent or too distant, or simply too interactive in their operation to be perceived by direct, non-augmented observation, or from instances that happen to be at hand. We may consider, in this regard, the quark, the galaxy, evolution, the Renaissance, the calculus, imperialism, the Romantic movement, the Cold War, the virus, and the climate.

Movement from the concrete/observable to the abstract, back and forth, constitutes a recursive process whereby the shuttling process itself comes to improve our understanding of both the specific and the general. An example from the current corpus is from Breslyn and others (2016, [5]). They focused on the topic of sea level rise (SLR) and on both students in the middle school years and undergraduate pre-service teachers programs. They interrogated these groups' understandings of three elements: the causes and mechanisms of SLR, the scale and representation of SLR, and the impacts of SLR. Drawing on the close analysis of the students' and pre-service teachers' responses, Breslyn and others developed progression statements for four levels – from "simple" to "sophisticated" – for each of the three SLR elements.

Drawing on the "causes and mechanisms" element, as an example (p. 1485), they pieced together the progression of ideas and the relationships among them shown in Table 9 (and see Duncan & Hmelo-Silver, 2009). This we may consider their attempt to model an element of the Knowledge domain, and a possible template for assessment of complex topics in CCE.

Table 9: Four levels of understanding of sea level rise among middle school students and pre-service teachers (Breslyn et al., 2016)

Level 1 ("most simple")	**Level 2**	**Level 3**	**Level 4 ("most complex")**
• aware of global warming as a cause for SLR, but no statement of why global warming is occurring or to what extent; • aware of melting polar ice caps from media sources but no attribution of heat energy from global warming as a cause of ice melt.	• aware of ice melt resulting from global warming and its relationship to SLR but relating only to ice located at the poles; • understanding of SLR limited to ice melt with no consideration of factors not easily observed (e.g., ocean currents).	• a qualitative shift to explanations based on atomic and molecular phenomena, but no consistent reasoning about the role of atoms/molecules in this mechanism; • consider the melting of any ice as contributing to SLR; • beginning to shift conceptually toward considering how thermal energy increases the kinetic energy of water molecules and causes a volume of water to expand.	• aware of the role of thermal expansion of water and ice melt; • can explain how ice melt on land contributes to SLR; • consistently uses the atomic/molecular model to explain how thermal expansion contributes to SLR.

These key shifts may arise from increasing pressure of the gradually more complex manifestations of phenomena, associated with, in this case, SLR as a sign of climate change. They may also, however, arise from ideas and observations drawn from forms of thought and expression that are encountered in curriculum areas other than the sciences or geography, for example, from ways of describing historical or economic phenomena that are too fast/slow, and so on, to be congruently or commonsensically described and explained. Whatever the particular explanation in this case, it is clear that the perceptual availability of the object or process of inquiry can present the learner with a distinctive course of learning, and, thereby, the teacher with particular tasks in developing appropriate pedagogy and valid forms of assessment.

Roadmap #2: Pre- to multi-, to inter-curricular understandings

A further perspective on learning progressions is aimed directly at curricular formations in school (Waltner et al., 2019, [29], see esp. pp. 3-4). The movement here we can characterise in these terms:

- Level 1: pre-disciplinary understandings and statements about weather, climate and the biosphere ("simple accounts" from the descriptions above);
- Level 2: subject-specific competencies (increasingly complex discipline-related terms and ideas); and
- Level 3: highly domain-specific and potentially multi- and inter-disciplinary competencies.

Waltner and colleagues also included elements relating to Attitude in the KSPA framework "affect-, need-, and motivation-related competency features," along with values, (e.g., personal acceptance of the intergenerational idea of justice); and attributions of responsibility. That is, they found Level 3 to be also associated with maturing epistemological beliefs about the situated nature of empirical knowledge in CCE:

> *"The underlying affective-motivational traits become progressively more conscious on the way from Level 1 to Level 3." (p. 4)*

Roadmap #3: From congruent to non-congruent language and thought

Emerging almost eight decades ago (e.g., Artley, 1944) and intensifying over about the last 30 years, theorists and researchers in psychology, linguistics, and educational measurement have drawn attention to the ways in which the qualities of "literacy" evolve rapidly over the middle years of schooling as the curriculum disciplines come to shape and specify the textual settings for students' learning. Each curriculum domain puts the written word, and, over recent decades, its attendant modalities, to the work of establishing its distinctive body of knowledge and ways of knowing.[vii] This observation, with some variations in features and emphases, has been labelled "content area literacy," "disciplinary literacy," or "discipline- or subject-specific literacy."

In their detailed analysis of the evolving reading and writing demands facing students over the school years in the subjects of English, history, and science, Christie and Derewianka (2008) sketched an overall developmental trajectory. This trajectory receives its momentum from several developments in the use of the increasingly technical forms of language and other modalities, key elements of which can be illustrated by the progress from "congruent" to "non-congruent" language use.

At the congruent end of the scale, language is related to commonsense actions and knowledge via the simple collection of clauses, all at the same conceptual level, and the representation of processes as verbs, and objects as nouns. At the non-congruent end of the scale, the interest is in explicitly naming the kinds of relationships the elements display, so that they can be further elaborated and more responsive to movements from concrete to abstract objects of inquiry. These contrasts reflect a learner's ability to compact and thereby analyse, build on, contextualise, and connect ideas and phenomena.

As an example, we can examine the first sentence of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6, which reads:

> *1. Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. (IPCC, 2021, p. SPM-5, A1.1)*

One process – 'are caused' – is represented in the form of a verb. Other processes implicated here – observing, increasing, mixing, concentrating, resulting in, equivocating, and acting are shown as mostly nouns or descriptors. We can adjust this sentence to form a more congruently expressed version, like this:

> *2. Since around 1750, greenhouse gases mixed in with the atmosphere have increased, and we have observed this. This, we now know unequivocally, is caused by the way humans have acted.*

We see here clauses joined for the most part by simple addition – "and" – and processes (apart from equivocate) and things are represented congruently – processes appear as verbs, and things as nouns, including via the two uses of the term "this" to stand for complex combinations of elements.

A less congruent version than Example 2 might be this:

> *3. Greenhouse gases mixed in with the atmosphere have increased since around 1750, and we have observed this. We now know for sure that this is caused by human action.*

We can notice the potential for both specifying and generalising that the nouns mixture and human action afford compared to Example 2.

An even more non-congruent expression than Example 1 from the IPCC report might replace its sole remaining 'moving part' – "caused by" – like this:

> *4. Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally a result of human activities.*

The processes represented here – observe, increase, mix, concentrate, result in, and act – are now all nominalised, and efficiently compounded, most obviously in the opening noun group that is the subject of the verb "are": observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750. It is a compound packed with "activity," but grammatically without any processual "movement":

The verb “are” is static, simply marking equivalence, and the causal relationship is represented via the nominalisation “a result of.”

Note that all four of these versions are taken to be equally effective communications in a general sense, but that the curricular business of, in this case climate science, is best served when the condensation of a potentially complex process by nominalisation allows it to be further refined into more readily and economically expressed combinations of processes, allowing both more technicality to emerge, and the points to be made at a level of abstraction more appropriate to that emerging technicality. This is not “better language,” but it is the version of language that climate scientists have developed to do the work at hand. The task of a curriculum is not just conceptual; it is to develop, in tandem, the language toolkit by which that curriculum does its conceptual business.

Christie and Derewianka marked out a general “roadmap” that covered curriculum areas English, science and history with four “milestones”:

- early childhood, with simple commonsense knowledge expressed in congruent, largely spoken forms;
- mid-childhood to early adolescence, when commonsense knowledge becomes elaborated by expanding non-congruent language resources;
- mid-adolescence, when knowledge moves further away from congruently-expressed common sense; and
- late adolescence, when “uncommonsense” knowledge comes to be expressed in more specialised language via fully non-congruent resources that allow for abstraction, generalisation, and judgment.

From this linguistic perspective, assessing the capabilities of school-aged youngsters without attending to the role of schooling in the development of these resources and their strategic use across the school years is to miss the most pressing and complex demands those youngsters face. Similarly, not drawing on what is known about the features of the evolving linguistic demands of the curriculum, and the conceptual correlates of those demands, is to have teachers deal with learning challenges, in our case to do with CCE, without a technical framework on which to base their practice.

We have sketched three kinds of “roadmaps” for considering learning progressions in the area of CCE. While these operate at different levels of discourse, it is not difficult to see how they interact in practice, pushing and pulling along linguistic, conceptual, and epistemic development. All three approaches direct attention to the development linguistic, cognitive, and epistemic resources as inter-related reference points for any valid and practicable assessment of CC.

V Climate, learning, and literacy

We have argued that the term CCE presents at least two sets of challenges to educators aiming to provide defensible assessments across a range of educational settings. The first arises when we ask how planning, teaching, and assessing “climate” as a curricular object is different from assessing, for example, “mathematics,” “history,” or “science.” Is it best approached as a set of cognitive, socio-cultural, and linguistic resources for within-, multi- or inter-disciplinary learning? And what are the points of cross-curricular contact that might allow the emergence of new, developmentally critical understandings?

While the study of Earth’s climate is an educational topic that has conventionally been most at home in geography and science, in many jurisdictions, the study of climate (often under the rubric of “sustainability” or “environmental” studies) is seen, and sometimes mandated, as a topic to be addressed across the curriculum areas. This raises a series of questions about the topical aspects of climate that pertain variously across the range of curriculum/disciplinary settings in which it is encountered: How can learners’ capacity to address climate as a within-, multi-, and inter-disciplinary area of study be specified to the point of reliable and valid planning, teaching, and assessment?

One account of the contrasting characteristics and processes of the philosophical, cognitive, social, and cultural work to which reading and writing are put in the disciplines was provided by MacDonald

(1994). She categorised disciplines in terms of the different solutions they have developed for articulating their core activities: What fundamental issue does this discipline's practitioners inquire into – what is its "central puzzle"? And what kind of puzzle is that? In order to know about what? What have they come to regard as counting as a demonstration of that knowledge? What do they conventionally take to be the main purpose of conveying that knowledge? And is that knowledge to be simply articulated or promoted as well? MacDonald set out to map the basic distinguishing features of the various curriculum areas and the disciplines on which they draw in terms of how each discipline has evolved to address these general questions. A summary, along with some (admittedly debatable) examples, is shown in Table 10.

Table 10: Criteria and contrasts that distinguish academic disciplines (based on MacDonald, 1994)

Identification of "central puzzle"	diffuse vs. compact (e.g., anthropology vs physics)
Criteria for knowledge production	implicit vs. explicit (e.g., art appreciation vs history)
Socio-cognitive functions	interpretive vs. explanatory (e.g., literature vs. economics)
Socio-cultural functions	advocacy vs. knowledge production (e.g., citizenship vs. biology)

What are the implications of such a schema for learning about CC within and across the curriculum areas? The coupling of "climate change" with "education" combines:

- foundational aspects of learning in school settings (aspects of listening and interacting, reading and writing, literal and inferential comprehension, acquiring functional use of novel and technical vocabulary, constructing different textual genres in print and digital contexts, decoding and deploying meanings from multiple modalities, and the rest) with
- a complex array of formal aspects of knowledge areas (such as those MacDonald has outlined) with, potentially,
- an even more complex and diverse set of attitudes, customs, beliefs, emotions, and moral convictions.

One way of imagining this set of relationships is to ask how the curriculum areas might, in discipline-specific ways, illuminate the study of climate, and vice versa. While specialised epistemic work is done largely within the disciplines, a cross-disciplinary approach has the virtue of situating knowledge within authentic disciplinary knowledge-based practices and conceptual frameworks, as well as challenging each discipline to define more sharply its nature in terms of knowledge, skills, practices and attitudes called for in climate studies: The discipline scrutinises the construct CC, and vice versa.

It is a complex task to imagine "climate" as it may interface with the skills, dispositions, and customs that give shape, say, to English studies versus science versus history. But to avoid these complexities is to diminish the aspirations of even our most modest attempts to introduce learners (and, in some cases, their teachers) to climate science and climate change. Unlike familiar curriculum areas, CCE simply does not have a curriculum history that begins when future teachers were starting their own schooling, and was built on as they proceeded through their university education and professional training. Among both the parents and teachers of school students, therefore, there are no established understandings of "climate change" as a structured domain of inquiry, of established pedagogical traditions, and of assessment.

VI Conclusions and ways forward

VI.1 Researching the climate

It is clear that CCE has enjoyed substantial growth both as an area of curriculum and policy development and as a field of research. One recommendation we noted above is the need for input into this growth from a broader range of demographic, economic, and cultural communities. These two aspects of CCE's current historical moment – growth and breadth of input – have at least the potential to compete: CCE is a potentially contentious field of inquiry, and, as it becomes a more formalised area of study in schools, universities, and workplaces, and as an element of public education programs, increasingly intensive bureaucratisation may follow, and avenues for input thereby may become increasingly selective.

Several of the reviews outlined above noted relatively small numbers of empirical studies, in contrast with theoretical or conceptual position papers. This relates as well to the range of disciplines within social and physical sciences brought to bear in the study of CCE and the varieties of emerging methodologies and technologies that characterise those disciplines. One possible consequence of this, which became more evident the more we explored the teaching and learning of climate-related research, is that there is little agreement around the outcomes, general or specific, that educational programs are aiming for in this area. Clearly, the physical science of CCE – its physical, chemical, biological, economic, and socio-demographic facts – are necessary but not generally regarded as sufficient elements of CC curriculum. And while the emotional, normative, attitudinal, and practical dimensions of learning about CC make frequent appearances in these corpuses, these ideas assume a wide variety of forms.

An immediate task for the CCE research community, therefore, is to engage in the systematic development of a coherent and actionable progression of "outcomes." In turn, that means some more focused and broadly-based conceptual and theoretical debates about the outcomes and ongoing utility of CCE learning (including some relative newcomers to the field of CCE such as neo-psychoanalytic approaches to climate denial, e.g., Weintrobe, 2021). It is a task that also highlights the importance of incorporating the widest possible variety of communities and perspectives into the educational process.

A necessary element of a more systematic approach to a CCE curriculum is an understanding of the physical science of CC—not only of the concepts and insights developed by climate scientists, but also of the research and communication practices that give rise to these findings and to their publication and dissemination. This is useful from a curriculum perspective because a sole focus on CC concepts does not render these concepts transparently understandable. A CC curriculum needs to pay attention to the empirical, statistical and computational methods — more generally, the social and epistemic practices — that are constitutive of the practice of studying CC. This is particularly relevant when we recognise CCE as a novel, interdisciplinary field of work (Bush et al., 2019a).

Furthermore, the way CC findings are communicated to a wider audience is highly multimodal — recall the IPCC report mentioned above — and effectively impossible to follow without a grasp of statistical data visualisation methods. This calls for an alignment with elements of the mathematics curriculum as well as the curriculum for computational thinking. A deeper connection between these might be achieved through a shared focus on modelling (Bhattacharya et al., 2021; Weintrop, et al., 2016). Building students' familiarity with the practices of climate and CC science can start in primary school: Interactions with scientists and participation in authentic scientific practices are elements of environmental education that can also be readily put to service in CCE (Smith, et al., 2020).

VI.2 Schooling the climate

Many studies summarised above provide a range of "next steps," each along its own conceptual and methodological trajectory. Over and above those specific lines of work, some general observations can be made.

First, as noted, several reviews expressed surprise at the small number of empirical research studies relative to the overall mass of publications and resources in the field of CCE. This may represent CCE's status as a relative newcomer in the area of educational research, calling for some "beginning" work in theoretical development and in the application of appropriate methodological resources. Or it may express the contrary notion – that CCE is best thought of as a collection of existing, established traditions of curriculum, pedagogy, and assessment, and, as such, it needs novel material resources for classroom use rather than any distinctive, new forms of "what-works" type research.

Second, not surprisingly, much of the available empirical research has been conducted in secondary science classrooms, and there is significantly less on primary and early childhood students (but see Malone et al., 2020). Some recent research exists that explores the reasons for this (see, e.g., Audley et al., 2020). An explanation that immediately comes to hand concerns cognitive and emotional "readiness." Ginsburg and Audley (2020), for example, interviewed 22 early childhood educators and administrators across nine early childhood education centres in the United States. They used Davis' (2010) distinction between teaching and learning in, about, and for the environment, and found that "most participants promoted activities in the environment, such as children spending time outdoors" (p. 42). While these early childhood educators saw respect for and love of nature as foundational to later learning, almost all of them wanted to include more extensive treatment of sustainability in their activities with the children but did not because of the "misalignment of educators' and parents' goals regarding sustainability education across all measures of education" (p. 57).

These observations point to the relationship between the formal curricular content in school and the views of parents and the wider community. A few days after the Australian students' climate strike in 2019, the Prime Minister of Australia at the time commented:

> *I don't want our children to have anxieties about these issues … the worst thing I would impose on any child is needless anxiety. They've got enough things to be anxious about. We've got to let kids be kids. (Prime Minister Scott Morrison, reported in Murphy, 2019)*

Clearly, the suggestion that topics such as CC should be taught at all raises foundational, potentially divisive questions about the nature of "childhood" – questions about comprehension, anxiety, and resilience – and thus about the rightful functions of formal education.

With regard to concerns about climate anxiety, there is a small but growing body of research that explores the various reactions of children and adolescents to climate issues. Here, our brief summary of that work is based largely on the review by Martin and others (2022).

The most common terms and concepts used they found to be 'climate anxiety' and 'climate worry' with occasional, various attachments such as 'environmental', 'eco-', and so on (e.g., Baker et al., 2020; Clayton et al., 2020). But in the research literature they also found a surprisingly wide range of closely related key terms used by psychologists and educationists: for example, solastalgia, grief, distress, fear, guilt, powerlessness, hopelessness, helplessness, anger, and grief. They found that some definitions and intervention studies are also specifically related to very specific behavioural manifestations, most commonly sleeplessness and panic attacks.

A central summary point for Martin and others is that the empirical research indicates that mental well-being impacts and negative emotions from climate change awareness are common among many child populations. They cited as examples research that shows approximately two thirds of teachers/parents said that their child(ren) were experiencing at least moderate levels of stress or anxiety about climate change (e.g., Baker et al., 2020). Further, 85% of Austrian and 89% of Australian adolescents reported that climate change was "probably or definitely something we should worry about" (Harker-Schuch et al., 2021).

But the review by Martin and others also strongly suggested that the pervasiveness of these effects can vary with demographic characteristics, most particularly by age. For example Kuang and Root (2019) found that older adolescents aged 15–18 years were more likely than 12–14 year olds to exhibit anxiety; most likely, the researchers suggested, because they had heard more about it.

In concluding, Martin and others noted some studies that suggest "how children cope with climate change, as well as their sense of hope and optimism, may play a role in both their mental well-being and engagement in pro-environmental behaviours" (p. 68). For instance, a study by Stevenson and Peterson (2016) showed that concern and hope about climate change were significantly associated with pro-environmental behaviour, whereas climate despair was significantly negative associated with pro-environmental action. The review ends with the customary call for ongoing research and more specifically for research with diverse populations. As Crandon and others (2022) put it, there is an urgent need for more systematic research to inform these issues, including "estimating the prevalence of clinical levels of climate anxiety in children and adolescents" (p. 130).

In a more recent study Ogunbode and colleagues (2022) conducted a comparative study of reported climate and environmental anxiety among adolescents and adults across 32 countries. They found that climate anxiety had a significant inverse relationship with mental wellbeing in 31 out of the 32 countries; greater anxiety associated with poorer mental health. They further found that climate anxiety was widely related to the kind of information to which people are exposed:

> *Not the mere volume of media exposure, but the content of the information and the amount of attention people pay to it. Information about climate change impacts appears more strongly linked to climate anxiety than information about climate change solutions. (P 12)*

They also concluded that, while reliable relationships between climate anxiety and environmental activism were evident mostly in Western and more affluent countries

countries, it is nonetheless the case that "climate anxiety has broad international significance as a plausible challenge to mental wellbeing" (p.12).

These studies have regularly concluded that more research is needed to better understand and address climate change related mental health issues. It is particularly clear that the issue of variability across geographic locations and cultural settings calls for more detailed attention (see, e.g., Skamp et al., 2021). For the purposes of this review, it is also clear that, as a profession, educators require empirically reliable guidance on what counts as 'negative' and 'positive' messages across age levels and sociocultural settings.

An additional theme in the research reports here concerns the nature, depth, and duration of CCE efforts. They are variously described in the reviews summarised above as short, supplemental rather than stand-alone, "integrated" into existing curriculum domains, and, overall, patchy. One result of this is seen in the variety of, often, intuitive descriptions of the learning goals of CCE programs. The complexity and contentiousness of this area is both reflected in and intensified by the increasingly diverse approaches to assessing outcomes. Bhattacharya and others asserted, as a major conclusion from their review, that curricular and pedagogical initiatives can be addressed in a systemic way only through the increasing use of validated, reliable instruments and measures, and that, in an area such as CCE, developing valid and comprehensive assessments constitutes a "a community-wide endeavour":

> *… not only assessments to evaluate individual student's (and teacher's) progress toward defined climate-related learning outcomes … but also observation protocols, instructional logs, surveys, and other instruments that can help researchers evaluate all aspects of climate education programming (Bhattacharya et al., 2020, p. 11)*

These reviewers also concluded that getting the tools used by practising scientists into teacher education programs and school classrooms means more than projects that use contemporary elements of expertise and the analytic and technological resources that support that expertise; it also means developing cumulative learning progressions of clear outcomes for both teachers' and students' development that provide these resources with observable sequence and coherence. This is an urgent recommendation from most of the sources used here. It seems clear that improving and consolidating on this front will have flow-on benefits for CCE.

VI.3 Developing the teachers of climate

It is only a mild exaggeration to claim that the preparation and ongoing support of teachers in the area of CCE emerges in these research reviews as a “meta-priority,” the priority that gives direction and coherence to the other priorities – classroom learning, continuity and trajectory across the school years, the recruitment of digital, online technologies, and the rest.

Bhattacharya and colleagues (2020), for instance, listed key scientific concepts and processes that are fundamental to an understanding of CCE but that show unacceptable levels of variability and outright inaccuracy among teachers:

- composition of Earth’s atmosphere;
- the function and nature of atmospheric gases;
- the concepts of energy budget, solar radiation, and energy transfer;
- the greenhouse and enhanced greenhouse effects; and
- understanding carbon uptake, release, and movement in the carbon cycle (Bhattacharya et al., 2020, p. 7).

To that list, Aksan and Celikler (2013) and Namdar (2018) have added that the teachers in their studies felt inadequate in how best to act on these key ideas pedagogically, as well as how to work with students on the material and human consequences of ongoing CC.

Researchers working on competencies/skills approaches have indicated some key general ways forward. Corres and others (2020) concluded that CCE involves complexity that arises not only from the interplay of scientific ideas and processes at the centre of CC inquiry, but also via its interface with potential emotional reactions in such a way that “the space for environmental values to evolve” can be developed in students, and, even before that, in the teachers themselves.

> *Future research should consider analyzing the impact of training courses fostering these emotional competences in terms of their contribution to developing educators’ emancipatory qualities with transformative potential. (Corres et al., 2020, pp. 20-21)*

But systematic research on teacher education has not been a visible priority in the area of climate change; in the words of Goller and Rieckmann (2022, p.19), “teacher educators as a group have been given scarcely any consideration”. In light of the relative immaturity of CCE research and the complexities inherent in bringing CCE into formal schooling, let alone teacher education (see also Pegalajar-Palomino, 2021), it seems ill-advised to wait for the development of a stable corpus of “what-works?” studies before developing formal, accreditable pre- and in-service teacher education programs. Meta-analyses and other forms of research synthesis depend for their validity on the availability of a large number of individual studies that develop and evaluate curriculum innovations systematically in comparable settings. In contrast, approaches to relating research-practice partnerships such as Design-Based Research, are particularly well suited to this stage of CCE’s development. They combine a problem-solving orientation on the local level with the advancement of theory and the development of organisational capacity, since the work takes place in the context of strong researcher-practitioner partnerships (Barab & Squire, 2004; McKenney & Reeves, 2012; Plomp, 2009).

VI.4 The climate of policy in CCE

Most of the research summarised above makes some mention of the significance of policy. The purview of discussion varies, some orienting to local, others to more jurisdictional issues, and some to international and global perspectives. Most draw attention, however, to the need for considerations not just of knowledge, or of individual attitudes and practices, but also of the need for teachers and students to understand the importance of co-ordinated, collective action. The approach to educational practice and research needs, for many of these researchers, to move rapidly beyond “problem-solver narratives” (Van Poeck et al., 2019) and toward the explication of those political and historical realities that have led to the current situation, and the variable economic and cultural effects of that situation in different sectors of societies, locally and globally:

Education systems will grapple not only with educating for climate change mitigation and adaption, but also with questions of how education policy should respond to climate inequities, such as differential historical responsibility for climate-modifying emissions. (Aikens, 2016, p. 20)

In their extensive review, Aikens and others, in fact, found few papers in the area of sustainability and CC education that explicitly examined the relationship between economic factors and educational policy. More generally, they reported a "dearth of research that examined education policy in relation to climate change," in spite of the relative frequency with which environmental degradation and national and international policy contexts were named as motivating an increased focus on educational policy (Aikens et al., 2016, p. 334).

Policy analyst Richard Elmore (1996) pointed to what he termed "the three conceits" of educational policy – assertions not generally believed to be true, but, nonetheless, practically, acted on as if they *were* true:

- The most recent set of reform policies automatically takes precedence over all previous policies under which the system has operated;
- Reform policies emanate from a single level of the education system and embody a single message about what schools should do differently; and
- Reform policies should operate in more or less the same way in whatever settings they are implemented. (Elmore, 1996, p. 499)

For Elmore, prior to researching an educational policy setting, there needs to be a focus on the initial improvement of practice, and, only in that light, on the itemising of policy ramifications:

We need more research… that takes the changing of educational practice as its central concern and treats the ambient policy environment as one among many factors that operate on practice, rather than treating policy as the focus and the primary determinant of what happens in districts, schools, and classrooms. (Elmore, 1996, p. 504)

In an educational field with the complexity and potential economic, cultural, and party-political reach of CC, this is an important observation: Policy development needs to keep one eye on educational research that can show positive, replicable results in terms of a broad range of climate-supporting learning outcomes; but the research suggests that it also needs to maintain a clear appreciation of how past and current policy settings themselves have come to shape CCE.

A policy issue that affects and is affected by both political and educational settings concerns nomenclature. In much of the above discussion, we have used the terms climate change, sustainability, global warming, biodiversity, and so on, as relatively interchangeable. The policy-related research collected in this corpus of reviews and instruments strongly questions this. Salas-Zapata and others (2017), for instance, argued in their conclusions that "'sustainability' as a term has become too variable in its uses to be any longer educationally useful," a term "that can mean, at the same time, a purpose, a dynamic behaviour and a set of social-ecological criteria" (p. 56). It can focus learners' attention on community practices that enhance, in local settings, greenhouse emissions, energy usage rates, or waste management without any attention to how such modifications might relate to broader, more extensive cultural or economic practices that call for extensive collaborations on a more urgent timeframe.

This terminological issue has two effects. First, "sustainability" is a term that can, in theory, be heard, and taught, without even an implicit reference to the need for change. As Salas-Zapata and others (p. 55) concluded, knowledge and positive attitudes regarding "sustainability" can be fostered among students and teachers alike without any apparent effects on their willingness to participate actively in more climate-friendly practices. Second, the breadth of the term's potential reference has permitted, and maybe even encouraged, the use of an array of potentially disconnected and incommensurate outcomes, assessment procedures, and educational materials.

So, next steps in that regard should include collaboration around the development of explicit goals and outcomes, and the organisation of these into coherent, cumulative progressions for teaching and learning across the school years. (A recent, highly detailed curricular example developed by Australian applied linguists is Hayes and Parkin, 2021.) Advancing on that front could be accompanied either by developing and making more explicit the use of the term "sustainability" as it applies to pedagogy and curriculum, or by replacing it with a more actionable set of terms that can specify and sequence the key physical- and social-science concepts for educational use (see especially Günther et al., 2022). As O'Flaherty and Liddy (2018) concluded, a similar set of specifications apply to the conduct of research in CCE:

> *[D]esigning and employing appropriate and adequate research methods to address the complexity and multiplicity of learning arising from Development Education, Education for Sustainable Development, and Global Citizenship Education requires further investigation and innovation. (O'Flaherty & Liddy, 2018, p. 1044)*

VI.5 The climate of assessment

Much of the educational research and development now centring on studies of climate, environment, and sustainability is motivated by the growing body of research on climate change. Public concern about climate change puts pressures on governments and jurisdictions to respond with relevant policies, including policies for formal and informal education programs. Earth's climate has long been a central topic in the school subject of geography. The development of educational programs across the range of curriculum areas, along with debates concerning the appropriateness of a version of climate science as a curriculum domain in its own right, together represent the public's sense of urgency that has grown only over recent decades. Like many dynamic, engaging educational topics, CCE, as a program of study, is an "institutionally immature" field. But demand for serious, defensible programs in CC will mean that it faces a potentially rapid growth spurt.

VII Conclusions

One often underestimated feature of CCE, as it appears in the materials collected for this review, is its status as a cross-curriculum provision rather than a curriculum domain in its own right. As summarised above, a key conclusion has consistently emerged regarding the inadequate preparation and ongoing support of teachers in this rapidly-growing and complex area of inquiry. But concerns about the quality, coherence, and currency of teaching and learning may well have even more to do with CCE's comparatively ill-defined nature and status: What sort of "educational object" is this? What relative weightings are assignable to its goals – knowledge, skill-sets, attitudes, and actions? What counts as "prioritising" it? The discourse about CCE is, in a sense, aspirational, as a supplicant domain of study, on the defensive from the outset, lacking a through-line history of materials development, pedagogical tradition, bureaucratic management, local institutional support, and community acceptance, and thus in constant need of arguing for its rightful place as a core program of inquiry.

Schools seem almost perfectly evolved to avoid, let alone prioritise, an educational object that relies entirely on "cross-curriculum activity." Were CCE an established, accreditable curriculum domain, there would not only be less defensiveness in justifying ongoing efforts in research, professional development, and policy, but those efforts would likely be more focused on progressions in learning, approaches to the assessment of students' work, evaluation of programs, and so on – the regular, organised efforts and debates that sustain and legitimate the trajectory of an established curriculum domain.

Over 20 years ago, concerns were expressed about the curricular status of climate and environmental studies in schools: "It was, perhaps, a mistake for environmental education ever to have become so identified with, and dependent upon the success of, cross-curricular approaches" (Scott & Reid, 1998, p. 216). More recently and in the Australian context, Kennelly et al. (2011, p. 211) concluded that the actual curriculum descriptors provided in the "Cross-Curriculum Priority: Sustainability" "do not amount to a coherent and substantial effort" that allows students to develop the knowledge base or the attitudinal dispositions, or the practical resources to which the Priority aspires. These concerns echo observations by British educational researchers, as revisited in Aikens and others (2016, p. 13):

> *Most analyses offered pessimistic findings on the success of cross-curricular integration: rather than infusion of sustainability, this approach was typically found to result in the marginalization of sustainability in the curriculum (e.g., Adedayo & Olawepo, 1997; Gayford & Dillin, 1995; Puk & Behm, 2003). (Aikens et al., 2016)*

So, a key policy decision, which has far-reaching implications for pedagogy, assessment, and for the appropriate range of input into curricular content, relates directly to the curricular status of the study of climate-related issues in schools and teacher education programs.

For Australia?

> *We must quickly achieve a much better understanding of Earth System dynamics in our continent and surrounding oceans, as well as contribute to a global understanding, as a necessary underpinning for managing Australia's environment proactively and effectively through the 21st century. (Steffen, 2015)*

Australians live on a continent that is well positioned to develop a rich and distinctive set of educational responses to these challenges, including programs in the area of environmental, sustainability, and CC studies. Australia offers much to international educational efforts, having:

- the sixth largest landmass, and the seventh largest coastline in the world;
- distinctive biodiversity profiles – ecosystem, species, and genetic – with many endemic native species in a variety of land and water habitats; and
- six major climatic zones – equatorial, tropical, subtropical, desert, grassland, and temperate – and an extraordinary range of ecologies.

Similarly, Australia is well-placed to make distinctive advances in the social, cultural, and economic aspects of CC-oriented curriculum in schools and pre- and in-service teacher support programs, having also:

- an Indigenous heritage, with a unique longevity, that includes traditions for land management and food sourcing (an early example is Green et al., 2010; and see McGinnis et al., 2020);
- a unique environmental footprint – a substantial carbon- and coal-reliant economy, with CO_2 potential that ranks as the third biggest fossil fuel exporter globally (Swann, 2019, Australia Institute, and Academy of the Social Sciences in Australia, 2020);
- a distinctive demographic profile, including a high level of urbanisation (ranked third among the ten largest countries) and multiculturalism (245 first languages spoken; ~30% of the population foreign-born); and
- strong, moderately centralised school systems staffed by systematically trained and accredited teachers with access to ongoing professional development.

So Australia has the responsibility and the opportunity to make a substantial, distinctive contribution to educational efforts in the general area of climate, environment, biodiversity, and sustainability.

Finally, along with documenting the work of teachers, teacher educators, professional associations, and educational policy-makers, this review points to the body of research that can now be put to work in supporting international efforts in CCE, and to the major role of social scientists in initiating and researching those efforts.

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Final Corpus for Instruments section

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i. The criteria are provided for both searches in the event that interested educational researchers, policy-makers, and practitioners can re-apply the search routines and update and refine the data bases.

ii. ((“secondary school” or “primary school” or “elementary school” or “secondary education” or “primary education” or “elementary education” or “school teachers” or “school students” or “K-12” or “K-16” or “teacher education” or “pre-service teachers”) AND (“climate change” or “sustainability education” or “education for sustainability” or “environmental education” or “greenhouse” or “ozone layer”) AND (“case stud*” or “ethnography” or “interview” or “survey” or “instrument” or “scale” or “inventory” or “assessment”))

iii. For instance, Clayton and colleagues (see Baker, Clayton & Bragg, 2020; Clayton, 2020; Clayton & Karazsia, 2020) developed a “climate anxiety scale” focusing on i) impacts on concentration and emotions ii) rumination iii) personal experience iv) efficacy about climate change, and v) sustainable behaviour.

iv. See Favier et al. (2021).

v. Lee & Barnett (2020) pointed to a direct relationship between these aspects of how climate change is characterised and the nature and extent of young learners’ concerns and anxieties.

vi. Examples include Christie & Derewianka (2008), Deng & Luke (2008), Freebody, Chan & Barton (2013), Goldman et al. (2016), Halliday & Martin (1993), Krogh & Jakobsen (2019), Lee & Spratley (2010), Moje et al. (2011), Shanahan & Shanahan (2008), and Spires et al. (2018).

APPENDIX

ACADEMY OF THE SOCIAL SCIENCES IN AUSTRALIA

CLIMATE CHANGE EDUCATION STEERING GROUP

Chair, Policy Committee

Sue Richardson

Emeritus Professor, Matthew Flinders Distinguished Professor, Flinders University, Member, National Sustainability Council, and of the Commonwealth Expert Panel on Climate Futures, https://www.flinders.edu.au/people/sue.richardson

Co-ordinator

Chris Hatherly

Academy CEO, and former Policy Director of the Australian Academy of Science, PhD Psychology, ANU, https://socialsciences.org.au/news/new-assa-executive-director/

Members

Annemaree Carroll

Professor and Deputy Associate Dean Research, Faculty of Humanities and Social Sciences, Professor of Educational Psychology, School of Education, University of Queensland, Affiliate Professor, Queensland Brain Institute, National Centre for Youth Substance Use Research, https://education.uq.edu.au/profile/191/annemaree-carroll

Stewart Clegg

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Peter Freebody

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