Citizen science for cooler schools: improving heat resilience in educational settings

Abstract

The increasing number, duration and intensity of extreme heat events associated with a changing climate demand investment in preparedness in settings where people learn, work, play and live. The success of interventions and resilience initiatives relating to community level emergency and disaster management as well as future thinking on climate change adaptation is enhanced when communities are closely involved in the development and implementation. The Citizen Science for Cooler School's project (CS^2) was a 12-month pilot that explored heat risk in Queensland schools and involved students as scientists to learn about and consider ways to manage identified 'hotspots' on school grounds. Two schools in South East Queensland were selected after meeting eligibility requirements. In partnership with researchers, students in Science Technology Engineering and Maths (STEM) clubs used inquiry-based methods to understand the heat problem and its effects. They used scientific equipment to identify school hotspots and, during guided classroom activities, students planned projects to mitigate heat-health concerns. Alongside this student involvement was the development of the Heat Risk and Preparedness Toolkit that was co-designed by researchers and school staff. This paper presents the project's findings, recommendations for future testing and options for development and application of the project deliverables in more Queensland schools.

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Introduction

Trends in climate variance indicate hotter summer seasons with record-breaking heat, along with more frequent and prolonged heatwaves (Domeisen et al. 2023; Franklin et al. 2023; McNeilly Smith et al. 2023). For Queensland, a state that already has significant summer heat complexities compounded by high humidity levels, managing health risk from heat is critical (Government of Australia 2024; Mason et al. 2023). Heat risk reduction and readiness is not simply climate adaptation; it is a fundamental form of emergency management in Queensland, now and into the future (QFES 2019).

In this context, components of this project align with Queensland's Continuity, Disaster and Emergency Management Policy (Queensland Government 2022) in particular the prevention, preparedness and response elements (see Figure 1) and align with the state's Disaster Management Framework (Queensland Government 2024a).

Extreme heat events across Queensland and Australia pose significant health and safety risks to many specific cohorts. Young children (in the case for this project, primary school students) are particularly susceptible to heat stress because of their specific high activity levels and immature self-regulation via behaviour (Vanos 2015). The concurrent presence of elevated temperatures and humidity can increase heat-related risks for school children to hazardous levels during the school day (Vanos et al. 2016).

In the 2024 summer in Queensland, the 'state-averaged summer maximum temperature was 1.18°C above the 1961-1990 average, which is the highest since 2019-20' (BOM 2024, para. 2). These warming trends

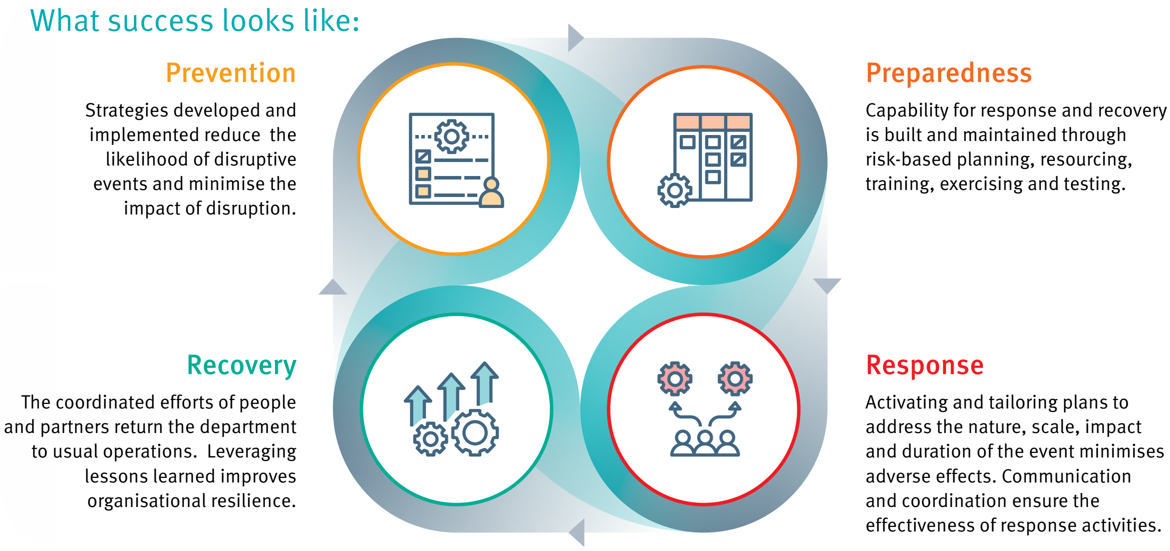

Figure 1: Department of Education Disaster and Emergency Management Framework.

Source: Queensland Government (2024a) https://ppr.qed.qld.gov.au/attachment/continuity-disaster-and-emergency-management-framework.pdf

align with national and international longitudinal data of global climate change. Additionally in Queensland, the complexity of a large state with a diversity of climate zones requires management of heat in schools at a grassroots level. School managers and staff need to be aware of local conditions and site risks. Managing exposure risk within school settings and targeting where children are often located during hotter parts of the day is one important tactic. A study by Rusli et al. (2018) outlined the role of children in the design of ways to mitigate the effects of urban heat and this study engaged primary school students towards similar goals.

This paper reports the findings and lessons from the pilot citizen-science research project Citizen Science for Cooler Schools (CS^2). Using 2 public primary schools in South East Queensland as case studies, the project's goal was to examine the heat-related risks on school campuses via the development of a STEM extracurricular activity. In parallel, a heat-health mitigation toolkit was developed that could serve as a starting point for an emergency system for extreme heat events in numerous schools. The toolkit could be used to generate insights and learnings for future direction. The research had 3 foci:

1. the citizen-science element of engagement as method and approach
2. the Heat Reduction Toolkit produced by the project
3. the project insights and learnings.

Literature review

Extreme heat and school settings

Extreme heat and heatwaves are increasingly being included as extreme weather events and are captured in emergency management planning in Australia (Bolitho and Miller 2017). Extreme hazards like severe storms, fires and floods are present in many school crisis plans, however, while heat is considered in education policy (Queensland Government 2024b) and resources exist that link youth education to disaster resilience (AIDR 2021), the extent to which extreme heat is considered in the emergency management context in Queensland schools is under-explored. In Australia, the long school summer break coincides with a large part of summer but the shoulder seasons and the beginning and end of summer fall within school terms. It is anticipated that changes in climate will see an extension of summer conditions in the coming decades (BOM 2023, 2024).

According to Shortridge et al. (2022), heat safety culture in schools has received relatively little attention. Contemporary literature focuses on 2 domains for understanding and reducing heat risk in school settings. First is the thermal comfort of students inside classrooms and school buildings (de Dear et al. 2015; Jindal 2018; Katafygiotou and Serghides 2014; Kwok and Chun 2003). Second is managing exertional heat stress during school sport and outdoor recreational activities (Bergeron 2013; Bergeron et al. 2011; Kerr et al. 2014). Quantifying and reducing incidental heat exposure during outdoor classes, recess and lunch periods, travelling to and from school and school entry and exit points where students and parents may congregate, has not been explored in the literature.

Shortridge et al. (2022) investigated school heat readiness and child heat vulnerability in Phoenix, USA. They found that students were physically and academically negatively affected by extreme heat inside and outside the classroom. Experts they consulted understood this and widely supported extreme heat readiness plans accounting for site-specific needs within education precincts. Most notable was the finding that heat safety resources were often available but rarely fully used within Phoenix schools.

Antoniadis et al. (2020) specifically explored schoolyard thermal comfort. They discovered that landscaping materials and design styles commonly employed in the schools they studied often lead to high surface temperatures. Poor materials choice meant increased heat absorption from direct and indirect radiation that increased heat risk and associated health consequences for children. Evaluations of heat stress have also been conducted in playgrounds (Bäcklin et al. 2021; Pfautsch et al. 2022; Vanos et al. 2016) and outdoor sporting fields (Liu and Jim 2021). Typically, these studies were purely scientific in nature with little to no end user engagement through either co-design or citizen science. As a result, data collection was costly with sophisticated methodologies and equipment employed.

Outside the scientific literature, toolkits and practical guidance on heat risk and management in schools and school activities are becoming available in a few countries, including Australia. The Climate Council's 'Keeping School Kids Safe During a Heatwave' explores risk reduction measures in classrooms, during recess, lunch breaks and school sports days and offers advice on hydration (Hannah n/d). The Queensland Department of Education provides some policy guidance for heat risk management in schools and information about managing heat (Queensland Government 2024b). However, no individual school or site-specific guidelines are publicly available. Relating to whether schools remain open during extreme heat, Queensland Government online information indicates that:

> *Unless the principal or regional director determines that the school must temporarily close due to a disaster or emergency situation, Queensland state schools remain open and students are not sent home during periods of excessive heat or heatwave conditions. Staff manage risks associated with excessive heat at schools through a variety of strategies.*
> (Queensland Government 2024b, para. 2)

The Extreme Heat Policy (Sports Medicine Australia 2012) provides a biophysical model for predicting heat stress risk and recommends cooling strategies to mitigate heat stress risk in adults but is not specifically tailored for children. Research undertaken by Western Sydney University offers a comprehensive review of thermal comfort in school settings and environmental cooling opportunities (Madden et al. 2018). Key recommendations from this report are identification, testing and implementation of best practices for cooling to offset effects of rising temperatures on children's activity, health and learning. This highlights that more work needs to be done.

Citizen science

The most common conceptions of citizen science are where the public is enlisted in the process of data collection (Bonney et al. 2009), data analysis and data verification (Kelling et al. 2009) and evaluating program success and effects (Cooper et al. 2010). This forms an important connection between science and education. Most current citizen-science projects are large scale with an emphasis on involving adults in relevant issues internationally (Clery 2011), nationally (Trumbull et al. 2000) or locally (Kermish-Allen et al. 2019). The CS^2 project offers understandings about the application of citizen-science principles to the school setting and involving school-aged children, in this case, heat risks in schools. This real-world setting for the teaching component of the project aligned with current Queensland Department of Education principles of immersive learning in classroom settings as prescribed curricula (Department of Education Policy Officer pers comm 2023, see also the Queensland Department of Education 2024).

The application of citizen-science principles in schools is an emerging element within citizen-science projects with benefits such as increased understanding of science (Saunders et al. 2018) and a better understanding of the methods of science (Shah and Martinez 2016). Literature available on citizen science in school settings focuses on high school students, which is understandable as many of the concepts are quite advanced or are only addressed in high school settings. Additionally, as concluded in a review of 20 citizen-science projects with a student focus, a major barrier to embedding such projects within the curriculum is the need to balance research and educational outcomes (Nistor et al. 2019).

Generally, most schools have a set curriculum with learning objectives in relation to content, skills and attitudes, time bound by terms or semesters and assessment requirements that are state or nationally mandated. A set school curriculum contrasts with many citizen-science projects where specific learning may not be a priority. Instead, the aim is on knowledge or skills that are not in a curriculum and are not formally assessed and not temporally bound by the school year (Ballard et al. 2017). Nistor et al. (2019) argue that curriculum tension must be resolved and suggest that increased dialogue between researchers and schools will allow respective agendas and goals to be met when designing school-specific citizen-science projects.

Methodology

A case-study approach facilitated design and testing of age-appropriate science-based activities (curriculum or extra-curriculum) and design and testing of a heat

1. Index of Community Socio-educational Advantage, see https://saasso.asn.au/wp-content/uploads/2012/08/Guide_to_understanding_ICSEA.pdf.

risk reduction toolkit. The success of interventions and resilience initiatives is enhanced when communities are closely involved in their development and implementation (Robertson et al. 2021; Slingerland et al. 2023). The CS^2 project took a citizen-science and cross-curricula sustainability approach to raise awareness of heat exposure in schools. The aim was to build on the Queensland Government's Heat, Health, and Human Environment Sector Adaptation Plan Plus (SAP+) initiatives (Armstrong et al. 2018) and the Cooler Cleaner Schools Program (Queensland Government 2022).

The project was structured into 4 research phases (see Table 1) and was designed and implemented by a multi-disciplinary team including specialists from environmental health, urban planning, education, thermal physiology, architectural science and environmental science.

Two public primary schools in South East Queensland, one each from a metropolitan and non-metropolitan area, were selected as study sites. The schools were chosen based on their geographical location, potential for heat stress and socio-economic status (high vs low ICSEA[1]) with the aim to better understand the complexities and challenges of implementing such a project in those contexts. Hereafter these schools will be referred to as the Metropolitan State School (MSS) and Non-Metropolitan State School (NMSS).

Table 1: The 4 research phases of this project.

Distance	Operationalisation example
Phase 1	• School selection and engagement. • Identify existing heat policy and practice. • Analyse project constraints at each school. • Establish project advisory group. • Initial project interviews with teachers and administrators.
Phase 2	• Student unit of inquiry – 'how can we make the school more heat resilient?'. • Student fieldwork, identifying school hotspots. • Student data collection using handheld scientific instruments. • Locating static logging devices to measure temperature and humidity. • Ongoing school staff interviews.
Phase 3	• Collaboration between students, teachers and researchers. • Student design and application of heat risk reduction projects. • Design, refinement and application of bespoke heat risk reduction toolkit. • Ongoing school staff interviews.
Phase 4	• Final interviews with staff. • Researcher reflections documented. • Feedback provided by the advisory group. • Produce the overarching project report and outputs.

Using concepts in disaster resilience as outlined in the *Second National Action Plan for Disaster Risk Reduction* (AIDR 2024) and the Continuity, disaster and emergency management policy (Queensland Government 2022), including prevention, preparedness, response, recovery, the CS^2 project focused on prevention and preparedness with some response elements. Over the course of the 12 months, researchers worked with teachers, students and administrative staff to identify 'hotspots' within the school grounds and provide advice on addressing the risks. They also developed an inquiry unit implemented through the extra-curricular 'STEM club' that targeted heat-health risk.

Citizen-science principles of active involvement and a genuine science outcome (for hotspot analysis) and contemporary educational practice provide benefits to both science and society and involve citizens in all stages of the scientific process (ACSA n/d). These principles, in combination with an inquiry-based learning approach, facilitated the student engagement and education and enabled students to co-design mitigation and adaptation measures to address identified hotspots in each school.

For site-specific measurements, researchers provided the schools with handheld scientific instruments of one thermal imaging camera and one wet bulb globe temperature probe as well as supplying 5 temperature and relative humidity logging sensors with a data gateway for automatic upload to an online data portal. At the completion of the project, some of the equipment was donated to the schools for their ongoing use in STEM activities.

During the final stages of the pilot, researchers facilitated reflection on the project and discussed future directions with the members of the advisory board. Feedback was positive from all members relating to the success of the project. The project aims and findings were discussed and it was agreed that citizen-science projects like this could feed into longer-term governance for climate change and disaster preparedness (Sexton 2023, pers comm).

Developing toolkit components: the co-design process

A heat risk reduction toolkit was designed as part of the pilot project. The heat risk mapping process began as discussions between researchers and school staff. This allowed the research team to better understand school administrative processes and guidelines around heat, risk and mitigation. Staff strongly advised that guidelines for heat mapping and risk reduction should be accessible, concise and simple to use. They also indicated the project would need to sit outside the curriculum due to departmental assessment requirements, available time and resources. Despite sitting outside the curriculum, clear and evident links to the Australian Curriculum, Version 9 were made to the Geography, Science and Mathematics curricula (ACARA 2024a) (see Table 2).

After several months of data collection and prototyping, a preliminary toolkit was produced that considered elements of heatwave prevention, preparedness and response as well as heat risk resilience. This draft version was shared with staff to engage, apply and test. Feedback on the first draft was used to refine the toolkit with a final version produced for the one-year pilot. Taking on feedback and recommendations as each element of the project developed, the research team worked with staff to identify deliverables that were aligned with their practical recommendations and that they would use.

Ethics statement

The project received full ethics review by the Griffith University Human Research Ethics Committee as well as ethics clearance from the Queensland Department of Education. Ethics approval was provided on 7 September 2022, reference number 2022/641. Supplementary ethics clearance from the Department of Education was granted on 19 September 2022. All researchers had valid Working With Children Blue cards prior to any field visit to school grounds.

Table 2: Links to the Australian Curriculum.

Learning area	Content description (adapted from ACARA 2024a)
Geography	The management of Australian environments, including managing severe weather events such as bushfires, floods, droughts or cyclones, and their consequences (AC9HS5K05). Locate, collect and organise information and data from primary and secondary sources in a range of formats (ACH9HS5S02). Develop evidence-based conclusions (AC9HS5S05). Propose actions or responses to issues or challenges and use criteria to assess the possible effects (AC9HS5S06).
Science	Consider how people use scientific explanations to meet a need or solve a problem (AC9S3H02). Construct and use appropriate representations, including tables, graphs and visual or physical models, to organise and process data and information and describe patterns, trends and relationships (AC9S5I04).
Mathematics	Use mathematical modelling to solve practical problems involving additive and multiplicative situations including financial contexts; formulate the problems, choosing operations and efficient calculation strategies, using digital tools where appropriate; interpret and communicate solutions in terms of the situation (AC9M5N09).

Findings

School study sites

The MSS is a large school located in the greater Gold Coast Council area. At the time of inquiry, the MSS (ICSEA = 999)[2] had a student population of 649 covering prep to Grade 6. The MSS has a long running extra-curricular STEM club that successfully hosted the research pilot for the entirety of the project timeline. The project also included close involvement with the school principal and administration staff.

The NMSS (ICSEA = 920) is a small school located in the Scenic Rim region near Beaudesert. The school had a student population of 118 covering prep to Grade 6. The initial phases of school selection identified that this school did not have an extra-curricular STEM club. However, on further discussion with the school, one of the science teachers offered to start one and students soon became involved. The school was subsequently selected and the STEM club successfully ran the pilot study for the entirety of the project. The principal and administration staff were also involved in the pilot study.

School data for this section was sourced from the Australian Curriculum and Reporting Authority (ACARA 2024c).[3]

Hotspots in the schools

MSS

Nineteen ‘hotspots’ were initially subjectively identified by students, staff and researchers at the MSS. Initially, students conducted a walk around and ‘feels like’ exercise with the STEM teacher and 2 researchers. Students first were asked to describe how they felt in different locations, making a note of the locations where they felt warm or hot. Students then revisited those locations with scientific equipment to measure heat on several occasions to map a baseline. Once these initial sites were mapped, students discussed them with the research team and STEM teachers to select 5 locations that were then monitored by students for the remainder of the pilot study.

Figures 1 and 2 represent a selection of the spreadsheets created by and with students in the classroom and, hence, they have slight differences in data presentation. The in-class discussions on heat mapping and tabulating of data that lead to the selection of study sites demonstrates the interaction between the researchers and the students as learning activities.

2. Index of Community Socio-educational Advantage is ‘a scale of socio-educational advantage that is computed for each school … estimated by the National Assessment Program- Literacy and Numeracy (NAPLAN)’ (ACARA 2024b). *Guide to understanding the Index of Community Socio-educational Advantage (ICSEA).* Australian Curriculum, Assessment and Reporting Authority. www.myschool.edu.au/media/1820/guide-to-understanding-icsea-values.pdf
3. Data informing the school metrics was sourced from ACARA My School website. Specific webpage information and URL details related to each school is redacted.

NMSS

Using the same hotspot identification and monitoring process as the MSS, 13 'hotspots' were initially identified by students and researchers at the NMSS. Five of these were selected and monitored for the remainder of the pilot. Figure 2 shows the list of hotspots at the NMS and those selected for the pilot study have been highlighted.

Participating school engagement

An education package was designed on the topic of heat risks in schools using an inquiry-based approach. Following the stage of hotspot identification and selection of sites, students identified and short-listed potential heat risk mitigation projects using a decision making matrix. Students developed criteria and then used those criteria to judge the feasibility of the project ideas. Once projects had been selected, students were grouped into their projects with a project journal template so they could keep accurate records of their projects for the purposes of submission into the Gold Coast Schools Science Competition and the Queensland Science Contest.

Due to the depth of inquiry underpinning the education package and the audience that would need additional detail of the findings, a separate paper detailing the education package/unit of inquiry is in development. In this paper, we focus on the value of the education component to student learning, community engagement and school outcomes.

Student learning

The goals of the unit were to raise heat risk awareness among students (and vicariously their parents and the community) while addressing key educational priorities. These are to show explicit links to the existing curriculum, development of higher-order thinking and having students address real-world issues, accessing and understanding authentic texts, using technology as a communication and research tool and to analyse and process data. Essentially, to communicate with real-world audiences for the purpose of making a difference in their lives or the lives of others.

While the students were encouraged towards self-directed actions on heat mitigation, most of the student groups chose to not mediate hotspots directly (e.g. via infrastructure changes or environment modification) and instead focused on cooling the human body. Only one student group at the MSS elected to design shade infrastructure for their STEM room. Table 3 shows that the students presented their projects across 4 categories at the Queensland Sustainability and Science Showcase in 2023.[4]

Broader student engagement

The student STEM club activity sparked interest from other students who were not directly involved in the pilot project. This was evidenced in discussions with teachers:

> *Students are looking and going 'ohh, what are you doing?' And when Harry takes them around the school to take photos, readings and things like that. … So, there's that curiosity about what they're doing.*
> (MSS STEM Teacher, February 2023)

4. Sustainability and Science Schools Showcase 2023, see www.chiefscientist.qld.gov.au/science-comms/programs-events/sustainability-and-science-schools-showcase.

		Atmospheric readings			
Locations	**Amnt of activities**	**WGBT**	**Air temp (TA)**	**Globe temp (TG)**	**Relative humitity (RH)**
Outside Admin	Low	24.8	26.7	43.7	35.1
Year 4 eating area	Low	23.8	36	37.7	39.4
Native forest		22.2	26.3	41.1	32.8
B'ball court (undercover)	Low	21.8	26.2	37.8	35.9
B'ball court (open)	High	21.7	27.7	39.2	33.1
Native forest		21.1	26.7	32.1	38.5
Oval	High	20.3	25.5	37.7	37.8
Library		20.1	26.4	26.7	38.9
STEM room	Low	19.8	25.2	24.8	45.3
5A		19.3	23.9	31.3	38.1
Prep playground		18.2	24.8	33.8	38.4
Prep C					
Oval					
4C					
Prep A					
Kiss and go					
Administration					
B'ball court					
Senior playground					
Music room					
STEM room deck					

Figure 1: The initial hotspots identified at the MSS - yellow highlight shows locations were selected for monitoring, salmon highlight indicates a missing sensor after installation.

Location	Averages				WGBT (Heat stress)		TA (Air temp)		TG (Radiation)		RH (Humidity)	
	WGBT	TA	TG	RH	1	2	1	2	1	2	1	2
Prep eating area	19.8	24.85	28.35	46%	19.8	19.8	24.8	24.9	28.5	28.2	44%	48%
Hall	19.65	25.35	25.5	44%	19.3	20	25.3	25.4	25.1	25.9	42%	45%
Green shed	19.6	24.7	27.65	42%	19.6	19.6	24.6	24.8	27.5	27.8	43%	42%
UCA	19.6	24.4	27.7	39%	19.4	19.8	24.2	24.6	28	27.4	45%	34%
Sand pit	19.55	24.5	27.75	43%	19.5	19.6	24.1	24.9	28.1	27.4	44%	43%
Table at W end	19.5	25.35	26.7	41%	19.4	19.6	25.1	25.6	26.5	26.9	41%	41%
Outside admin	19.35	24.85	26.95	45%	19.1	19.6	24.6	25.1	26.7	27.2	48%	42%
Senior playground	19.35	24.45	26.75	41%	19.4	19.3	24.5	24.4	26.6	26.9	40%	41%
Court	19.3	24.85	29.15	39%	19.2	19.4	24.7	25	28.7	29.6	38%	39%
Year 6 breakout room	19.2	25.3	25.95	44%	19	19.4	25.2	25.4	25.8	26.1	42%	45%
Junior playground	19.1	24.65	26.75	43%	18.9	19.3	24.5	24.8	26.7	26.8	42%	44%
Year 4/5 classroom	18.9	25.3	25.1	47%	18.8	19	25.1	25.5	25.1	25.1	53%	40%
Table at E end	18.35	24.7	25.5	37%	18.1	18.6	24.4	25	25.7	25.3	37%	38%

Figure 2: The initial hotspots identified at the NMSS - yellow highlight shows locations selected for monitoring.

School outcomes - policy, risk reduction and school mapping

Suggestions from the pilot in the school setting included rescheduling school events to cooler periods and times of day, reducing physical activity at certain times, providing additional hydration and using cool refuges such as greenspace, shade and airconditioned indoor areas. Incorporating these suggestions into school and departmental policy and guidelines as informed by discussions with Queensland Education Department officers during the pilot could be tested for in future research developments. For example, heat risk identification and management could be linked with preexisting school auditing cycles to ensure school heat mapping is known to managers including cooler refuge spaces that can be used as retreat on hotter days, as outlined in the pilots Heat Risk reduction Toolkit. During the pilot, teachers acknowledged that there was a change in the way school managers responded to hotter days, with one teacher saying:

> *I've been teaching for 10 years—15 years actually, and never have we had a withdrawal of play. So those days where it was really, really hot, they had a 15-minute play and then they were withdrawn to undercover areas.*
> (MSS STEM Teacher, February 2023)

Table 3: Project titles and categories displayed by students at the Sustainability and Science Schools Showcase in 2023.

School	Category	Project
MSS	Environmental action	Creating a school garden: a place to cool down
MSS	Communicating science	Inferno: the boardgame
MSS	Technology and engineering	Automatic sunscreen dispenser and personal air-conditioning unit
MSS	Technology and engineering	What's the best way to keep our classroom cool?
NMSS	Science investigations	What's the best way to cool yourself down?
NMSS	Technology and engineering	Cool shoes: keeping your feet cool
NMSS	Technology and engineering	Cool hat: keeping your head cool

The Heat Risk Reduction Toolkit

A co-designed Heat Risk Reduction Toolkit was developed with resources designed to support prevention and preparedness elements of risk reduction. Preparedness items and event checklists were drawn from academic resources, government policies and guidelines and grey literature.

The toolkit has 5 components or steps:

- Step 1: An instruction page that defines 'heat risk' and explains how the 3 functional toolkit sheets work together.
- Step 2: Heat risk analysis and mapping process that describes the equipment required and how to conduct a heat risk mapping process.
- Step 3: A heat preparedness checklist that guides the user to assess and prepare for heat events before they happen.
- Step 4: An extreme heat event checklist that guides the user to manage student activities and access to safe places during a heat event.
- Step 5: A spreadsheet of mid- to long-term mitigation activities that could be adopted at a school to reduce heat risk.

The toolkit can be used by schools at any time of the year. Elements of the toolkit link together and form an auditing cycle that shows the relationships between the different parts of the kit and how they connect to existing school risk reduction processes. Given the co-design element of the creation of the toolkit and auditing cycles, researchers were guided by teachers and principals to align the kit components with current school health and safety review cycles. Feedback from educators and school administrators was that any resources created needed to be easy to use and accessible:

> *... sometimes there'll be these toolkits that are quite in-depth [and] involved and they stay on the shelf in the library because no-one has time to use them.*
> (MSS STEM Teacher, February 2023)

Since the study's conclusion, incorporating feedback, and further discussions with advisory group members and practitioners in emergency management, the researchers consider the auditing cycles for the heat mapping and preparedness could be included in guidance from the Department of Education related to disaster and risk management. Additional research, application and testing of the toolkit would be needed to confirm this potential.

The heat risk analysis and mapping process (step 2) was co-designed to be a simple and practical exercise. Minimal equipment is required for hotspot identification and suggestions of methods and approaches are explained in the toolkit instructions.

Emphasis is placed on administrative control, hydration and education in the heat preparedness checklist (step 3) and the extreme heat event checklist (step 4) to reduce identified heat risk, including during an active or emergency heat event. Administrative controls can be very effective to protect the health and wellbeing of students and staff on hot days. For example, cancelling outdoor activities on days exceeding specific temperature and humidity limits, restricting activities to cooler parts of the day and keeping students inside in airconditioned spaces are all effective in reducing heat risk in school.

Discussion

Heat as a 'disaster' event

School settings present several challenges to observe, measure and mitigate heat risk (Antoniadis et al. 2020; Shortridge et al. 2022). Children can be susceptible to heat (Vanos 2015) and the heat risks may vary depending on the ambient temperature, humidity, wind speed, solar radiation, children's clothing insulation, activity levels and individual health conditions (Vanos et al. 2016). This combination of variables adds complexity to how staff can manage or mitigate heat risk. Additionally, school settings vary greatly in design, layout, architecture, age and local climate.

Administrative controls that might work in a large modern school in a sub-tropical coastal hinterland could differ greatly to a small school in a regional drier climate. This is pertinent in Australia where sport and physical activity throughout the entire year are key elements of the school experience. In recent years, Queensland teaching spaces have been airconditioned to provide a level of thermal comfort throughout the year (Queensland Government 2022). Even so, there remains many parts of a school campus that can be heat risks coinciding with lack of shade, peak times of temperature, increased physical activity and built environments such as sports and assembly halls that are not easily airconditioned or well ventilated.

Basic risk reduction principles of mitigation, preparedness, response and recovery (AIDR 2024) also cover extreme heat risk and call for audits of high-risk areas, preparation for heat events and responding appropriately during hot weather. Preparation mechanisms discussed with participating schools included adaptation of the physical environment, scheduling activities and cooling the body. Responses to heat stress also consider climate adaptive measures to reduce the 'general' heat of school grounds (outside of specific heatwave events) that bridges risk reduction and climate adaptation domains. Examples of heat mitigation included:

- activity scheduling:
  - planning school athletics carnivals in cooler months
  - changing high intensity activities to cooler times
  - allowing time after play to rest in a cool place
- cooling the body:
  - increasing access to water and including information on good hydration practice
  - adapting school uniform materials, fit and style
- modification of the school environment:
  - building shade structures (e.g. hard cover and shade sails)
  - altering gardens and school grounds to increase vegetation, trees and gardens.

The approaches to heat mitigation in each of the school grounds were based on the research team expertise, underpinned by empirical evidence and literature. While school-based approaches were discussed with staff, it was not within the pilot project's scope to design or implement such approaches. This is due to the time, cost, necessary changes to school policy and guidelines as well as departmental approvals required. Schools are a vital element of communities and school heatwave management should be included within local emergency management processes and guided by state policies.

Application of heat preparation and adaptation tools in practice

This study confirmed the considerable time constraints experienced by staff to embed new processes and guidelines into school administration. Thus, the toolkit was designed to be easily incorporated into existing practices. School staff identified the components of the toolkit that could be carried out by student leaders in support roles, which is a practical measure to alleviate time pressures on staff.

The preparedness and heat event checklist items vary from low cost (e.g. scheduling changes, rescheduling sports carnivals to cooler months) to high cost (installing hydration stations and changes to uniform materials and style). Preparedness approaches require adoption by whole-of-school communities as they require support from the school administration, of the parent and caregiver communities as well as teaching and other staff.

Pre-emptively reviewing the school year calendar allows for administrative changes to be made to reduce heat risk. For example, swapping track and field events to cooler months appears to be a simple example. However, representative sport (e.g. athletics) may require national level coordination so that school athletics calendars could be aligned with regional, state and national titles events. What emerged during the pilot was a need to prepare for heat events:

> *… being able to plan for something in advance … if it's Sunday night, I open up the news and it says forecast for the week is going to be 31, 32 … and humidity is going to be above 70% every one of those days. Well, I want to know what that's going to feel like on the students … the direct effects. Like, you know whether that be student attention spans will be impacted, whether they're going to be more stressed, whether they're going to be more agitated because of the heat.*
> (NMSS STEM Teacher, February 2023)

A recurring discussion item during the study was the financial barriers of modification of school grounds. Infrastructure changes such as shade sails, gardens and hydration stations can be costly. Most of the costs for infrastructure changes are borne by the school and not necessarily by state governments. Fundraising was mentioned at both schools as a usual activity but rarely did this relate to grounds and heat reduction infrastructure. One of the teachers spoke of the trade-offs that could arise when funding infrastructure changes versus in-class teaching materials:

> *… and in terms of cost … if you came to the school and said this is what [infrastructure changes] you could do, it's going to have these benefits and it's going to cost this much money, I think that's going to be weighed up against what else that money could be spent on. I know that at the moment there's only one class that has … laptops, and … the laptops are starting to get a little long in the tooth. So, from a cost perspective, if it was me that was given the budget, I'd be weighing up what's going to have more long-term impact. A whole class set of laptops … that I can use every single year, or heat mitigation strategy for 12 weeks of the year. That's the analytical side of it.*
> (NMSS STEM Teacher, February 2024)

This suggests that future school grants will be required to provide the resources needed for heat preparedness and longer-term adaptation. Retrofitting schools is a costly measure and heat risk modifications may also create risk in other ways. For example, the installation of a shade sail could mitigate heat risk but the sail could be considered as a personal injury risk if damaged during a severe storm and add to maintenance costs.

Schools as a community education and heat preparedness hub

Engaging students and school staff as citizen scientists is a meaningful way of incorporating non-academic insights into real-world problems (Saunders et al. 2018). Involving young people in emergency education also allows them to contribute positively to understand and plan for natural hazards (AIDR 2021). The CS[2] project stimulated student learning about heat risk, climate change and school settings. Students applied new knowledge gained about temperature and heat monitoring to their school environment, measured and monitored heat in the school, identified hotspots and developed teamwork projects to mitigate heat or create ways to be cool:

> *So, there hasn't actually been any challenges from the delivery of the project and the students are really engaged. … we've actually got the opposite problem; how do we rein them in? Because now that they've got a taste of all these tools and different things that they're learning and different ways of learning … they're in from 7:15 in the morning to work on their projects.*
> (MSS STEM Teacher, February 2023)

Schools are common hubs of community engagement and gathering, which fosters school, family, and community partnerships (Cleveland 2023). These kinds of communities can build resilient community networks. One of the positive effects of the program created during this pilot was receiving feedback from staff that the engagement of students also engaged parents and guardians at home. The activities and education program filtered onto student homes and interest in the mitigation projects from parents and guardians grew as the project progressed. This 'at home' connection was evidenced by one school including the project in their social media posts and parents assisting with sourcing materials and equipment (MSS STEM Teacher, pers comm, 2023). Parental support was also demonstrated by their attendance at the student presentations at the Sustainability and Science Showcase in 2023. Additionally, one of the teachers said that the project had expanded reach throughout the student population:

> *But what is positive, is students have been talking to other students also with the news coverage of the story as well of the project students are coming in saying 'ohh, so what is it you're doing'? So, it's generating a lot of interest from students that weren't initially involved.*
> (MSS STEM Teacher, February 2024)

Key to implementing some of the heat preparedness and heat event suggestions and the longer-term heat adaptation investments will be the support of the school community. This may include the raising of necessary funds. When asked about fundraising for school infrastructure changes such as a shade sail, one NMSS STEM teacher said:

> *I could definitely see that there would be parents that would want to get involved with that, absolutely. If it was put forward to the school, then I think then the Student Council and the Leadership Team that work with them to do fundraising. The fundraising could be channelled over a year or 2 or 3 … but I could definitely see that fundraising could be done.*
> (NMSS STEM Teacher, 2023)

School administration support and time to make changes in physical activities and sporting endeavours and restrictions on activity should be provided. For example, students, parents and teachers will require time to adjust to new school management relating to heat events and changes to calendar events and uniforms. Support will be required for staff to learn the optimal use of cooling locations and time will be needed to incorporate any increased costs and policy changes associated with hydration.

Due to the 12-month timeline of the CS^2 project and the citizen-science approach taken, the project emphasis on heat mitigation in each school focused on student-led projects. Attention to other mitigation was limited due to constraints in time, resources or data to make recommendations on infrastructure changes. For example, shade structures can reduce heat risk in playground areas, however, staff indicated that there was no budget available for this work. While the final sheet (step 5) in the toolkit is a spreadsheet that lists potential infrastructure changes, these were general recommendations and suggestions. Suggestions were also not specifically aimed at either of the project schools. An in-depth heat study would need to be conducted at a school for recommended architectural and infrastructure changes.

Consideration of heat monitoring requires a balance of methods that consider cost, technical knowledge, information and communications technology (ICT) infrastructure as well as departmental security policy, precision, accuracy and need. Should this monitoring also involve students, then simplicity of use and data visualisation are key factors. For these reasons, simple handheld scientific equipment is recommended, like that employed in this pilot study.

ICT policy and infrastructure became apparent as limiting factors for this case study research. For example, after deploying the automatic temperature and relative humidity sensors and data gateway at the NMSS (the regional school location), weak cellular data coverage meant the gateway was unable to connect to the 4G network. After some trouble shooting, the gateway and sensors were abandoned and manual download temperature and humidity sensors were deployed.

Feedback from teachers at both schools indicated that students did not regularly interact with nor use data gathered from site location devices. Additional research is required to explore why this was so, or whether local deployment of site devices is necessary in lieu of other readily available meteorological data available in most Australian locations.

Recommendations and conclusion

Further development and testing of the toolkit is needed to refine its application, efficacy, effect and usability in school settings. This could include a broader range of climate zones, school types (larger schools, vertical schools, diversity in school age) and school populations (high cultural and linguistic diversity, student or staff disability).

In relation to data gathering, while the handheld scientific instruments (particularly the thermal imaging camera) were well used in the pilot, there was minimal student use of the real-time and scientifically rigorous sensor data generated. Given that general weather data is widely available, further testing of student interaction with such data is needed. Other considerations for the development of the toolkit could include engagement with the Outdoor and Environment Education Centre Network, equipment sharing between schools, and expansion into an online resource such as a dashboard.

Revision and application of the education component of this pilot is also warranted to understand how the involvement of students is maintained in other school settings. While this education package was designed as an extra-curricular activity with STEM club students, feedback from the Queensland Department of Education indicated that the package could be included in classroom activities as citizen-science approaches are already employed in Queensland school settings. This will strengthen the alignment of the education package with current curriculum pedagogies. In parallel with the refinement of these resources, embedding heat as part of school-based disaster planning will be key to successful implementation of school-based heat preparedness and mitigation. This can be assisted by drawing on resources already available such as the Disaster Resilience Education for Young People (AIDR 2021).

The pilot was successful in meeting its aims by producing and testing a preliminary Heat Risk Reduction Toolkit alongside an extra-curricular STEM heat-related activity. Future research to upscale the study to address this study's recommendations, revisit and refine the education component and further develop and test the toolkit is warranted, important and timely particularly given the changing and warming climate.

Extreme heat should be recognised as an important hazard, alongside other climate-related extreme events. As the world warms, we need to be prepared and have the tools to protect the health and wellbeing of communities from this growing issue. Schools are learning places for children, working places for teachers and other school staff and community hearts for parents and carers. The day-to-day operations of schools can present a heat-health risk due to the kinds of activities, duration and potential exposures to those who gather there.

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