Ways of Thinking in STEM-based Problem Solving

Teaching and Learning in a New Era

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Chapter 2

STEM in a changing world

'Insider' and 'outsider' perspectives

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Introduction

Science, technology, engineering and mathematics (STEM) skills play a central role in developing innovative products and services that contribute to a country's economy. UK government reports highlight the significant financial contribution that engineering and science-based industries can make to overall national prosperity and in terms of meeting future energy, health, security and research and development (Roehrig et al., 2021). It is this perspective that often drives arguments about the need to promote interest and participation in the specific disciplines of science, technology, engineering and to a lesser extent, mathematics (National Audit Office, 2018; Wong et al., 2016). However, policy directives and reports tend to focus more on traditional STEM approaches that emphasise the individual discipline knowledge of the four STEM silos, resulting in a somewhat narrow view of STEM literacy and education. Similarly, many educational organisations in the UK also promote STEM learning and professional development that are mainly orientated towards specific disciplines and less about the integration of STEM subject material and their synergies.

The value of interdisciplinary approaches has long been advocated by STEM researchers, such as Bybee (2013), with a number of interdisciplinary models being proposed, such as the hierarchical framework of Vasquez (2015). There are noted challenges about the concept of integrated STEM, including the equitable balance of all disciplines (English, 2016), the ambiguities of integrating four distinct content disciplines in respect of pedagogical approaches (Hallström & Ankiewicz, 2019) and questions about the depth and long-term integrity of distinct epistemic process (Tytler et al., 2023). However, benefits of interdisciplinary approaches include associations with project-based or problem-based learning, which encompass characteristics such as being student centred, presenting challenging tasks and promoting creative and strategic thinking processes for addressing obstacles and solving problems (Skilling, 2020). In addition, integrated project approaches promote different and/or multiple perspectives and require learners to work collaboratively, which promotes discussion, decision making, reflection, shared responsibility, agency and autonomy—factors that are associated with positive motivation and student engagement (Skilling et al., 2021).

However, there are potential constraints and challenges that integrated STEM activities may impose at the classroom level. One potential barrier, especially at the secondary school level, is that, in many education systems, teachers have a specific disciplinary background, which can hinder integrating the subjects across disciplines. Given that "an important aspect of a teacher's identity formation involves their identification with the subject they teach" (McIntyre & Hobson, 2016, p. 143), it may not be easy for teachers to accept the epistemologies of the subjects that they did not train in and translate them into appropriate pedagogical strategies. Research also suggests that teachers tend to have little knowledge of other school subject curriculum (Al Salami et al., 2017), even when a relatively adjacent subject such as mathematics for science teachers

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(Wong & Dillon, 2019). Despite teachers' interest in STEM education, these factors combined with practical barriers to STEM integration such as timetabling and assessment (Herro & Quigley, 2017) can discourage teachers from integrating STEM subjects in their classroom.

Resolving these philosophical, pedagogic and practical differences is not obvious. However, we argue that there are other affordances of an integrated approach to STEM education that offers an expansive view of STEM education without detracting from the importance of STEM discipline knowledge and skills. By including social elements and concerns that are important to learners, there is an opportunity to establish STEM education as personally significant to individuals and in contexts that are relevant to their communities. In this way, being STEM literate is shaped by and more closely aligned to those immersed in and affected by STEM issues.

For example, research that challenges the technological and growth perspective of STEM education emphasise the importance of meeting the humanistic and personal needs of citizens (Alsop & Bencze, 2014; Ma, 2021; Zollman, 2012). The humanistic orientation to STEM education resonates with individualised and personalised learning in respect to young people and their concerns about global issues and disruptive events. Ma (2021) suggests that there have been insufficient discussions about STEM education from humanistic perspectives and less opportunities for STEM learners to critically reflect on issues such as sustainability and ways of living in the world (Zollman, 2012). While the importance of personalised learning is becoming more prevalent, there is insufficient STEM education research that represents the experiences, needs and values of young people. Further, the range of technical skills and cognitive competencies which can be embedded in integrated STEM activities and programmes would benefit from further exploration to understand the attributes that individual learners can benefit from. Characteristics such as metacognition, self-regulation, systems thinking, problem-solving, deductive and inductive reasoning, collaborative ways of working and so on, are important competencies to promote in young people (Skilling, 2020), but in what ways can these characteristics serve to enhance STEM literacy in the short and longer term?

Growing a competent insider *and* outsider

These emerging changes and challenges necessitate rethinking the aim of STEM education and the meaning of STEM literacy. While we acknowledge that there are multiple ways to conceive and categorise the aim of STEM education, this chapter centres on the *learners* and their relationship to STEM. Feinstein (2011) argued that scientifically literate people are 'competent outsiders' to science, and able to see the relevance of science to the things they care about. Similarly, mathematics literacy emphasises using mathematical skills and concepts in everyday situations and in disciplines that do not necessarily require specialised training (Jablonka & Skilling, 2018). The positioning of mathematics within the UK curriculum includes statements about being a creative discipline, and critical to science, technology and engineering (DoE, 2014). Extending this conceptualisation, and noting that an individual's formal and informal relationship to STEM can be multifaceted, we propose that STEM literacy is situated in an ongoing dialogue between the self as a competent outsider and the self as a competent insider (Figure 2.1). In the first mode of engagement, STEM learning aims to develop an 'insider' who is familiar with STEM as a body of knowledge, a way of thinking and a set of epistemic and social activities. This can be based on learners' agency, interests, aspirations and identities in relation to STEM. In the second mode of engagement, where the learner is positioned as an 'outsider' to STEM, we can consider the learner as a social being, living in an increasingly complex society and dependent on the knowledge and expertise of others (Osborne et al., 2022). As members of the community, learners should be able to recognise the interrelationship between issues in their community and the STEM enterprise, which manifests itself in a variety of ways.

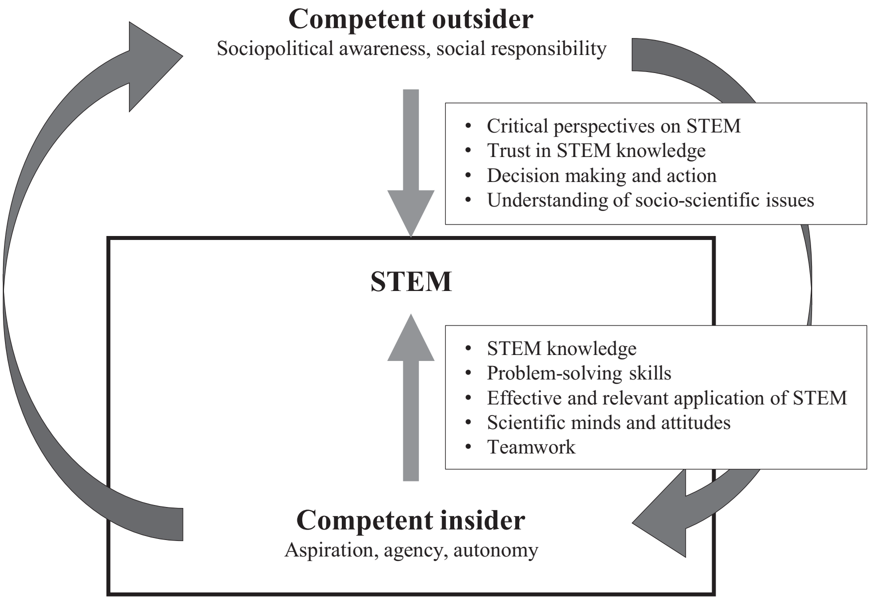

Figure 2.1 A model of STEM literacy.

In Figure 2.1, the curved arrows connecting the outsider and the insider imply that the development of STEM literacy is an iterative process and a dialogue between selves inside and outside the STEM enterprise. This process allows for occasions where the individuals' position may be more orientated towards the 'insider' or 'outsider' perspectives as well as capturing shifts between them. This way, we believe that this model of STEM literacy is applicable to the education of both future STEM professionals (equipped with an 'outsider' perspective, including the sociopolitical relevance of their work) and the general public (equipped with an 'insider' understanding of how STEM works).

We see the need for STEM education to offer alternative and flexible ways for supporting young people's current and future interest in STEM education, to address their beliefs, values and needs, and broaden conceptions of what it means to be STEM literate. Therefore, the research discussed in this chapter reflects a shift away from emphasising the economic and utility values of STEM education, to better understand 'what matters' to individual learners in the context of an increasingly STEM-orientated world. This more contemporary conceptualisation of STEM literacy that considers both the insider and outsider perspectives is transformative and meaningful for individuals and their education and support intrinsic motivation, for addressing issues affecting their communities and society more broadly.

Expanding conceptions of STEM literacy: Personal significance and societal concerns

To illustrate the importance of expanding conceptions of STEM literacy to include matters that are of personal significance and concern, two diverse studies are outlined in the following section. These examples represent two different ways in which an individual can engage with the STEM enterprise, as an insider as well as outsider. The two studies involved collaborative settings (one with upper secondary students in the UK, the other with preservice teachers in Korea). The studies explore what is valued in respect of learning in different contexts and awareness of the insider and outsider perspectives. Although each study has a nuanced focus on particular tasks, activities, processes and interactions, they each require the participants to engage in critical reflection and decision making that are essential components of STEM literacy.

Study 1: Valuing what is personally significant to learners

In respect of developing STEM literacy and enterprise, the students involved in a 'Robot Project' were mainly situated as a competent 'insider' reflecting aspects of interest, agency and autonomy; however, references to the future application of the students' robot knowledge and skills provide glimpses of the competent 'outsider' perspective. The Robot Project investigated the beliefs of a team of school students (Grades 10–13; 15–18 years-old) from a secondary school in England. Over 14 months, the students designed and constructed several heavy weight robots as an extra-curriculum activity facilitated by their Design and Technology teacher, and were tested in robot competitions. The research included one-to-one interviews with 12 members of the school Robot Team (grades 10–13, ages 15–18) and the teacher, and workshop observations. Reports of students' beliefs about STEM subject learning in respect of robot building and how learning processes were promoted have been reported previously (see Skilling, 2020). In this chapter, the macro motivation theory of self-determination has been used to frame the students' inner motivational resources they exhibited in respect of the robot-building context. Self-determination theory (SDT) refers to an individual's basic needs, goals, regulation types and orientations acknowledging that students are likely to have different reasons to perform (or not) at school, and these reasons are reflected in the way they engage in learning and result in different educational outcomes.

The three basic psychological needs of SDT include: autonomy, competence and relatedness (Deci & Ryan, 2012). Autonomy refers to voluntary choice, self-directed behaviours and self-control. Competence relates to self-importance, sufficiency and enthusiasm for taking on challenges and solving problems. Relatedness is the need for feeling connected, accepted and belonging. Associated with these needs are an individual's goal orientation (for performance or mastery), motivation for achieving one's goals (intrinsic or extrinsic) and the extent to which motivation for achieving goals are regulated (autonomously or externally controlled). The Robot Project provided opportunities for meeting these three key student needs and related motivational and affective factors.

Autonomy

Being able to regulate one's own actions and behaviours is a central notion of autonomy. Appleton et al. (2008) proposes that student self-determination can be facilitated in several ways, such as orchestrating student opportunities for decision making, setting up situations where students are more likely to succeed and enabling positive relationships between students. Three autonomous characteristics reflected in the robot-building environments were categorised as figuring things out, freedom to decide and self-direction.

Figuring things out: Students needed to make decisions about enabling the robot to operate and to identify what needed fixing when things went wrong. For example, student S4 stated:

> When you have certain pieces of chassis and it doesn't fit the weight limit, or something else doesn't fit… then you have to figure it out…if something goes wrong, you'd have to find out a way or and then fix the problem…you'd need an order of things to do.

Figuring out why things went wrong was also perceived as a learning opportunity by student S1, who said, "the best way of learning is to get something wrong and then find out why it was wrong…know why the next thing you're doing is better".

Freedom to decide: The student members agreed that the robot projects were "very much led by us and we were making the decisions…" (S1) and that "It's good he [the teacher] trusts us to get on with it…he is able to step back and leave us to it so that we can gain something you can't gain if he just tells you…" (S1). Another student reported that although they would run ideas past the teacher, "it's us that make decisions…it just gives more independence…more confidence to think about ideas" (S3). This view was corroborated by the teacher who stated that, "I haven't got the right answers and there's also so many different ways of doing things…it's not a case of right or wrong". He also confirmed the importance of building student confidence in their decision making and they "need reminding that they do know what they're doing and also that I don't have the right answer".

Self-direction: Several students discussed ways of being proactive in getting things done: "You need to always have a job. If you haven't got a job to do, …you need to be asking people what can I do right now?" (S7). Collaborating with the team and follow the team captain for guidance and support was valued, with student S6 reporting: "She [team captain] just points out roles that you need to do, get things done …unless you can't do them and then you usually get taught and then you can work on developing your skills even more".

Competency

This aspect of SDT highlights the value of being effective in one's pursuits, and to exercise capacities to seek out and master challenges (Reeve, 2012). Being a unique and nascent project, the students needed to draw upon their academic knowledge, and understand how this could be applied in a project-based learning environment. This required thinking conceptually about the whole project and its phases, including: ideation and design aspects; using CAD; identifying specific components and relevant materials; understanding electrical and mechanical systems; and developing workshops competencies (e.g., learning to weld, using a lathe, cutting steel).

Developing and connecting knowledge: Being able to conceptualise processes for and connecting academic knowledge relevant for building a heavyweight robot was encapsulated by student S5 who said:

> It's like a series of systems…. I think design is a huge part of it…how your robot differs from everyone else…designing the chassis. Then you have to think of all the things within that… engineering and how your design will work so that you are changing your design based off your engineering limits…and that can move into physics looking at the stress and strain in the material, and then you are also designing the electronics and how that will fit in.

Developing skills and techniques: Students reported that learning new skills developed their levels of competency. For example, Student S9 reported:

> When we first started, I did a lot of the wheels and I did a lot of chains and I was the person everyone went to for that…then I became like the welder…and for 'Expulsion (robot name)' I did all the battery things, on changing over the connectors. Now…when something needs to be done, I can just do any part.

Student S4 reported how developing a unique skill was helpful for inducting others: "I knew about different techniques and skills …like welding [but] I haven't done it that way before" and "if you're doing it by yourself you learn more and then you can teach other people in the team".

Solving problems: Not only were there many problems to solve throughout the robot build, the project itself was perceived by the teacher as a problem-solving exercise that would push the students:

> It's about problem solving and giving the pupils the opportunity to face a real-world problem that there's no answer to…I'm not in a position where I can give the right answer, so the pupils have to think for themselves and there's also the very real chance of failure, which makes them work at their limits (T).

The students also commented about learning from solving problems and became adept at dealing with them, for example: "Obviously at the start it was lots of creativity and we had to create a robot completely from scratch, but now [we] have built more and we know the design flaws and what works well, so now it's really logical thinking" (S7); and "I think the second time we were more well positioned … because we knew what we were coming up against…so you visualise what you could come up against and how you can solve that problem" (S1).

Relatedness

Relatedness reflects the needs of individuals to establish emotional bonds and attachments to others so that there are strong interpersonal connections resulting in caring and authentic relationships with others. This was reflected through supporting each other through teaching, feeling connected and working towards shared goals.

Teaching each other: The building of the robots was a new endeavour for the students. This resulted in learning skills and passing them on to achieve their shared goal. For developing technical skills for robot building, student S5 explained:

> Right at the beginning…our teacher didn't know how to weld, no one else knew how to weld, so our teacher learnt how to turn the machine on and do it. He taught [S1] how…and then basically she told the next person who took the next person and so on….I've now taught [S9] and I showed [S11] and I think [S6] and [S7]…So it's all like learning from each other because the teacher doesn't know any better than we do,… That's how you develop your robot and make it better…and passing that knowledge on… that's a really valuable part of our team.

Feeling connected: When asked about working as a team, student S7 stated, "I'm really grateful for the team we have, just because of how friendly and how you're not afraid to ask questions and you're not afraid to say 'oh how do I do this?'" Student S4 reported:"There's always somebody that will help you or guide you to learn how to do things: (S4). This student went to comment "…there's no pressure on you. You can just put ideas and yeah there's no one like 'that's a terrible idea'. Yeah, it's always constructive and that's really good about the team". Other benefits of working as a team in contrast to working alone because "then you'd only have one point of view on the robot. There could be lots of different things that could go wrong, so with a bigger team…people would work together and think of something else, a different way…" (S4).

Driven by shared goals: The students expressed a common desire to build a distinctive robot. Participant S1 explained that, "We wanted to do something that was really different and I think being young and creative allowed us to do that…we wanted to think differently and create something that worked but was different and innovative". However, despite wanting their robot to be the best, the students appreciated that by helping other teams in the competition reflected a shared achievement and although "everyone wants to try and be that team who builds the best robot out there that no one can beat… like everyone wants to win … but also … wants to help each other to win" (S10). Apart from building robots that work, shared interest in the area of STEM was also reported as being important, with student S1 reporting, "I think we're successful because we've learnt so much from it, and we've developed as people with skills in the STEM areas".

Section summary

From the student and teacher reports, the level of interest, autonomy and agency for making multiple and collaborative decisions in respect of the robot design and construction was high. This resulted in robust engagement, motivation and interest in seeking to build better and more effective robots (Skilling, 2020). Although the students had no prior experiences of building electro mechanical robots, they were able to draw on their collective academic knowledge (e.g., mathematics principals, knowledge of circuitry) and develop their product design skills and competencies. The students' capacity to readily apply their academic knowledge across STEM subject boundaries in this authentic and 'hands on' enterprise (Wan et al., 2023) is one example of the multifaceted potential of integrated STEM learning. The project required genuine collaboration, was motivational and promoted active engagement, aspects of STEM subject learning that warrant attention (Skilling et al., 2021). Additionally, shifts in the students thinking as competent 'insiders' to competent 'outsiders' were evident as they became aware of the ways they could flexibly apply and reapply their knowledge and skills in specific and generalised ways. Importantly, the research provides a rich insight to students' STEM beliefs and evolving understandings of STEM literacy.

Study 2: Critical STEM literacy for social issues

Given the close relationship between STEM education and democratic citizenship (Calabrese Barton, 2012), one important goal in a changing world relates to moving beyond the personal dimension of learning and develop critical scientific literacy that includes 'knowing-in-action' (Aikenhead, 2007) and engaging in sociopolitical action (Hodson, 2011). This view of STEM literacy was referred by Sjöström and Eilks (2018) as 'Vision III' that emerged following Vision I, focused on learning the content and processes of science, and Vision II, focused on the usefulness of science in everyday life. Decisions about social issues often require the consideration of various ethical, social, cultural and political factors along with science (NGSS Lead States, 2013). Individuals tend to make decisions about such socioscientific issues by relying on three classes of evidence: scientific evidence (i.e., hard scientific data), informal evidence (e.g., common sense, circumstantial evidence based on personal understandings) and wider issues that impinge on evidence (e.g., personal values and commitments related to the environment, the economy and morality) (Tytler et al., 2001). This suggests that engaging in personal and societal decision-making processes requires not only scientific knowledge but also a range of other abilities.

Among various issues related to science and society, disaster—whether triggered by natural or human-made technological hazards—is an emerging issue that requires urgent attention of STEM educators due to its impacts on humans (Oyao et al., 2015; Park, 2020). The UN Office for Disaster Risk Reduction (UNDRR) (n.d.) states that:

> Risk is ultimately the result of decisions that we make. We make decisions about the hazards to which we are willing to expose ourselves, we make decisions about where to build schools, factories, dams and dykes and how much to invest in disease surveillance and we make decisions about how our societies organise and care for vulnerable people and assets.

Such a characterisation of disaster risk assumes that it is the human decisions and (a lack of) actions that turns risk (natural, technological or biological) into a disaster. It is important, therefore, to consider ways in which STEM education can contribute to increase prepare for, respond to and recover from disaster, through the development of risk knowledge (Pietrocola et al., 2021; Schenk et al., 2019) and evidence-based reasoning skills (Sadler, 2004). Against this background, this section describes a study with preservice science teachers focused on disaster and identifies potential learning goals and associated challenges when teaching about disaster in STEM education. This will in turn reveal the value of growing a competent 'outsider' to STEM who can understand STEM in context and make informed decisions.

In the following, we describe a project with preservice teachers in South Korea to foster their STEM literacy in the context of challenging social issues such as disasters. In a two-week professional development workshop for undergraduate preservice science teachers, we used the humidifier disinfectant disaster as a case study to understand the role of STEM in understanding and tackling societal issues.

The humidifier disinfectant disaster was a tragic public health crisis in the late 2000s and early 2010s that affected as many as 950,000 (estimate) residents in Korea. During this period, numerous individuals, including infants and young children, fell victim to severe respiratory illnesses and fatalities due to the usage of toxic humidifier disinfectant products. These products, commonly used to clean and maintain humidifiers, contained hazardous chemicals, such as polyhexamethylene guanidine (PHMG). The tragedy prompted extensive investigations, legal actions and public outrage, ultimately resulting in significant reforms in consumer product safety regulations and increased awareness about the potential risks associated with household products (see Park et al., in press, for a detailed account of the disaster).

We used the humidifier disinfectant case as an example for a number of reasons. Firstly, there was a good deal of scientific knowledge about the disaster. By the time we held the workshop, eight years had passed since a number of products had been officially identified as the cause of an unidentified mass lung disease in pregnant women. The government investigation into the disaster included retrospective and prospective epistemological studies and animal experiments conducted by expert groups, which resulted in a high degree of certainty about the scientific facts of the disaster. The existence of a scientific consensus made the discussion of accountability and responsibility easier—compared to situations where the science is still emerging—which in turn made it easy to discuss actions to be taken. Second, the disaster challenged the traditional concept of a disaster as an event that occurs for a relatively short period of time in a particular place. We can trace the humidifier disinfectant disaster back to 1994, when it first appeared on the market, or to 2000, when the company was advised to carry out animal testing but chose not to. In this sense, it is a 'slow disaster' whose effects are not limited in time or space. In this way, the disaster serves as an effective example for preservice teachers to discuss various aspects of contemporary risks related to science, technology and health.

The workshop comprised two- to three-hour sessions and incorporated lectures, group activities, presentations and discussions. The sessions aimed to enhance preservice science teachers' understanding of disasters, their connection to science and society and their ability to incorporate disaster examples into science lessons. Group activities involved tasks like creating timelines, concept maps and infographics based on an investigation report of the humidifier disinfectant disaster. In the first session, the focus was on the HD disaster's context. The second session delved into science's role in disaster causality, societal connections, industrialisation, capitalism, uncertainty, and how disaster can link to various elements of the national curriculum for science. The workshop encouraged participants to critically engage with the disaster's scientific, social and educational dimensions that are of relevance to individuals' lives as both an insider and outsider to STEM. At the end of the workshop, the participants chose a disaster case of their interest and develop a science lesson plan for high school student. In the following, we describe the potential outcomes of learning about disasters that the participant suggested and how they incorporated these into lesson planning.

Knowledge of the nature of science and technology

Learning about disasters can provide students with a unique lens through which to understand and experience the complexities of science and technology. The study of historical and contemporary disasters can foster an appreciation of the dynamic relationship between science, technology and human society (Park, 2020). In particular, analysing the causes, effects and responses to disasters from a scientific perspective can highlight the different roles that science and technology can play in preventing, mitigating and sometimes creating disaster risks. Furthermore, the interdisciplinary nature of disaster studies encourages students to consider the ethical, social and environmental dimensions of scientific and technological decisions.

We found that the workshop was successful in providing an opportunity for participants to consider different modes of science, in particular what is often referred to as post-normal (Funtowicz & Ravetz, 1993) or post-academic science (Ziman, 1996). Participants recognised that this type of scientific activity differs from academic science in terms of the purpose of scientific research. In the context of the humidifier disinfectant disaster, they understood that researchers in industrialised settings are more vulnerable to external demands for profit, which can compromise their ethical standards and social responsibility. They were able to articulate how market forces can lead to neglect of safety protocols and biased interpretation of data and evidence.

While participants reported increased knowledge of these issues, their views on teaching about them in secondary schools were more complicated. During the workshop, P1 appreciated the nature of the 'risk society', which is characterised by new types of risks arising from human activities that are invisible and not bound by time or space (Beck, 1992). While appreciating this 'dual' nature of science, which both reduces and produces disaster risk, he said that teaching about it can lead students to see science as a threat, which he considered dangerous. This sentiment was shared by other participants. Given that disaster risk can often be exaggerated by the media, he felt that the emphasis should be on equipping students with the ability to critically evaluate information about risk.

Increased resilience to disasters

As much as the study of disasters can enhance learners' understanding of STEM, it can also play a key role in strengthening disaster preparedness and resilience within communities (Park, 2020), by providing insights that can inform effective mitigation strategies and response plans. Learning from past disasters can be crucial to developing measures such as urban planning, early warning systems and infrastructure improvements. In addition, understanding the intricacies of disaster management, including the use of advanced technologies, enables individuals and organisations to respond more quickly and effectively when disasters strike.

The participants appreciated the value of teaching about disasters in increasing resilience. P5, for example, believed that 'anyone can be affected by disasters', which makes it necessary to teach about them to facilitate prevention and response. Similarly, P14 noted that learning about building collapses and airplane accidents can help them prevent disaster 'when students get a job and work'. As a way to increase resilience, P9 proposed a problem-based lesson for secondary students where the students form an emergency management centre to respond to an imaginary disaster, use scientific analyses and processes to come up with a response plan. These examples demonstrate that the workshop was effective in facilitating preservice science teachers' abilities to relate STEM learning to disaster resilience.

One thing to note about these reactions is that disaster resilience is not a traditional goal of science learning as perceived by science teachers. While most participants were in favour of teaching about disasters, P13 was not convinced "whether it would be worth spending class time on disaster in secondary *Science*", although the national curriculum did have disaster-related learning goals (Park et al., 2023). Similarly, P11 thought that "it would be nice to learn about disasters … because it can motivate interest" but only when time allows. In particular, he was concerned that 'students' knowledge of basic science is getting weaker these days' and content knowledge should be prioritised over disaster. These reactions suggest that preservice teachers perceive disaster as, although useful to learn, less central than the content knowledge of science.

Critical thinking and engagement in social issues

Disasters, whether natural or human-induced, can have profound and far-reaching consequences, including loss of life, destruction of property, disruption of essential services and long-term economic and social challenges. Learning about disasters can stimulate students' interest in social issues and their active participation in sociopolitical action (Alsop & Bencze, 2014; Hodson, 2003). As students delve into the complex web of factors that contribute to disasters, they can uncover the profound influence of societal inequalities, inadequate policies and systemic vulnerabilities. This realisation can foster a sense of empathy and social responsibility as global citizens. By understanding how disasters disproportionately affect marginalised communities and exacerbate existing inequalities, students are motivated to seek solutions and advocate for social justice. Learning about disasters can mobilise them to engage in discussions, campaigns and initiatives aimed at reducing social vulnerabilities, influencing policy decisions and promoting greater community resilience. In the meantime, students can learn about how technology can mitigate (e.g., identifying potential hazards) and create (e.g., developing new chemical products) risks in modern society (Park et al., in press).

In the workshop with preservice science teachers, it was clear that they recognised the importance of students developing critical thinking skills in the context of social issues. P12 had long been interested in "addressing participation, pseudoscience, blind trust in science, and anxiety about science". She found that disaster could provide an ideal context to critically discuss such social issues in the classroom. Similarly, P13 said that "… the less trained people are in science, the more you seem to fantasise about it … I find it interesting as well as scary that people thought it's okay to drink a disinfectant that kills germs". In short, learning about the humidifier disinfectant disaster including its scientific and societal aspects helped preservice science teachers critically reflect on the relationship between STEM knowledge and broader social issues and develop links to teaching science in context.

Section summary

Overall, Study 2 illustrates how the goal and scope of STEM learning can be expanded to accommodate the emerging needs of society and grow a competent 'outsider'. With disaster as an example of such needs, we described how examining a human-made health disaster can provide preservice teachers with an opportunity to critically rethink the role of STEM in society and the purpose of STEM education in a changing world, which would be a crucial step towards educating competent outsiders. While the participants recognised the close relationship between STEM and disaster and found much educational value in teaching about disaster to future citizens, they anticipated practical barriers to putting such beliefs into action. These findings point to the need for preparing teachers who have broader views on the goal of STEM education in schools, providing more opportunities to reflect on the role of STEM in society during their pre- and in-service training, and creating more space for implementing STEM education to critically address issues in society. In other words, teacher education programmes should place more emphasis on an expanded conception of STEM literacy that encompasses the insider and outsider relationships that learners have with STEM. This will help STEM teachers to move beyond the purpose and epistemology of their own academic backgrounds and draw on different perspectives within and outside STEM to support students' knowledge, attitudes and skills needed in a changing world.

Discussion and conclusion

The two examples that we used in this chapter, each with adolescents in England and preservice teachers in South Korea, illustrate the values of STEM education in a changing world. We used robotics and disaster as contexts that represent contemporary challenges with high relevance to STEM and to explore the benefits and potential challenges of adapting STEM teaching and learning in a way that responds to social changes. The two examples illustrate that the value of STEM literacy can extend beyond serving future STEM workers to educating citizens who can work both autonomously and collaboratively, and who are aware of STEM-related social issues that affect individuals and society (Alsop & Bencze, 2014). Based on the educational benefits identified from the two studies, we propose an extended model of STEM literacy based on the dialogue between the learner as a competent 'insider' and 'outsider'.

More specifically, we propose new and expansive notions of STEM literacy which speak to three important aspects that reflect a more contemporary view of STEM education. First, there is a need to *broaden the scope of STEM literacy*, with an emphasis on the merits of design and engineering in respect of critical and analytical thinking about pressing social issues. This moves beyond the traditional content-knowledge focus of the four STEM disciplines to include community and global concerns connected to climate crises, environmental and sustainability issues. Given that many of today's pressing social issues have a STEM basis, STEM literacy should be seen as essential to the personal and social lives of all individuals, rather than a concern for a small group of people working in the STEM sector (Sjöström & Eilks, 2018). This expansive view of STEM literacy would be facilitated through curriculum reforms that move towards integrating STEM disciplinary knowledge and pedagogical approaches.

Secondly, the approach to facilitating STEM literacy should shift from *individual-focused learning to community-oriented learning*. Educators and policymakers should recognise and value STEM literacy formed through a social process and connected to the personal relevance of individuals and in the contexts of service to community and society (Roth & Lee, 2004; Tolbert & Bazzul, 2017). The case studies provided two ways to achieve this: by creating a collaborative environment through which students can appreciate the value of working together to construct STEM knowledge, and by employing a socially relevant and acute problem as a context for learning various aspects of STEM including how it works, which can be transferred to other contexts. In sum, STEM literacy in a changing world should aim for learners' engagement in STEM-related issues in their personal and social lives, based on their critical understanding of disciplinary and epistemic bases of STEM (Bybee, 2010; Cavalcanti, 2017).

Finally, *providing support for teachers* is imperative. Coupled with curriculum reforms, teacher educators can help teachers recognise the need for STEM literacy, realise the potential of integrated STEM education and overcome conceptual and pragmatic barriers to developing their own STEM capabilities. Initial teacher education curricula need to be more explicit about the personal significance and connections to community and society as a goal of STEM education, and tailor approaches for different groups of teachers. Given that primary teachers are interested in teaching integrated STEM but often feel unprepared in content and pedagogy (Shernoff et al., 2017), more research efforts are needed to identify more specifically the barriers that teachers can encounter and effective support to reduce such barriers. For secondary teachers, given that the challenges often arise from specialisation and subject identity where teachers tend to train in only one content area (Park et al., 2023; Thompson, 2023), providing training on design-based, contextual learning can help teacher overcome the disciplinary barriers (Enderson et al., 2020).

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