Navigating the lifelong learning boat through uncharted water

Patricia McLaughlin
RMIT University, Melbourne,
patricia.mclaughlin@rmit.edu.au

Belinda Kennedy
RMIT University, Melbourne,
belinda.kennedy@rmit.edu.au

Julianne Reid
RMIT University, Melbourne,
julianne.reid@rmit.edu.au

More than ever before, Australian tertiary graduates will rely upon innovative use of knowledge, work-readiness skills, and advanced multi-disciplinary understandings to solve future domestic and workplace problems. This is critically evident in STEM disciplines, where global trends increasingly focus upon the need for multi-disciplinary, industry-related approaches that maximise opportunities for future employment and lifelong learning. However STEM learning and teaching remains, for the most past, discipline-content entrenched. The evidence starkly indicates that Australia is falling short in educating future STEM graduates: something different has to be done! The STEM Ecosystem project: Water Innovation Challenge (WIC) at RMIT University created opportunities for staff and students from different disciplines to work alongside industry mentors in a multi-skilled team to design, build and present innovative water sanitation solutions for a local indigenous community and a Bangladesh community. The real-world problem necessitated a paradigm shift away from discipline-based knowledge transference towards skills for the future. The project utilised approaches such as negotiated curriculum and assessment; self-directed, flexible participation in learning; use of social media as a learning tool and multi-disciplinary teamwork. Results from student surveys and interviews indicate that this project directly enhanced students' work-readiness skills and recognition of the importance of problem solving using multi-disciplinary understandings. Students reported greater self-confidence for tackling future workplace challenges. The project and its outcomes have implications for how learning and teaching occurs in Australian universities; it challenges traditional understandings of learning and teaching and has the potential to create significant impact on the calibre of future STEM graduates.

Keywords: multi-disciplinary; STEM disciplines; work-readiness

The STEM Boat.

The importance of STEM (science, technology, engineering and mathematics) disciplines for the future economic and social well-being of all Australians cannot be under-estimated: 75% of the fastest growing occupations require STEM skills and knowledge (Becker & Park, 2011; INSEAD, 2014). As Australia moves towards the future, it is clear that STEM disciplines will underpin a differentiated, adaptable economy that is globally competitive. STEM research will, more than at any other time in history, contribute knowledge to a world that will rely upon a continuous flow of new ideas, technologies and applications. The opportunities that will flow from competitiveness in these global economies will benefit all Australians. Increased participation in future global economies is linked to STEM-related tertiary education. The Chief Scientist (2012) outlines this opportunity:

> An education in STEM fosters a range of generic and quantitative skills and ways of thinking that enable individuals to see and grasp opportunities. These capabilities—including deep knowledge of a subject, creativity, problem solving, critical thinking and communication skills—are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future.(p.7)

The demand for a well qualified multi-disciplinary future workforce in STEM disciplines is escalating. The Organisation for Economic Co-operation and Development (2012) has highlighted the supply of skilled multi-disciplinary professionals in STEM, as an urgent global problem. This increasing global demand for "new" multi-disciplinary STEM graduates is a result of a number of factors:

- the growing use and impact of information and communications technologies **inter-woven** across all STEM disciplines;
- the high rate of innovation fuelling rapid application of scientific advances in multi-disciplinary products and processes;
- the growth in more complex global **interacting** problems (climate change, global security etc); and
- the shift to more knowledge-intensive industries and services, not reliant upon single discipline responses.

There is widespread concern that, as a nation, Australia will not be able to participate in these global opportunites. The number and capacity of STEM graduates Australia produces from tertiary institutions is inadequate (West, 2012). The multi-disciplinary STEM skills required to adapt to jobs and technologies that don't yet exist will continue to become increasingly important, as will the ability to access, filter and interpret knowledge across new non-disciplinary boundaries (OCS, 2014; OECD, 2014)

Increasingly attention has turned to the capacity of STEM academics to address the global demand for "new" multi-disciplinary STEM graduates. STEM academics are central to meeting this increasing demand and improved workforce participation. The Australian Council of Deans of Science (2012) have highlighted that universities have a major role in meeting this demand. As Kennedy, Lyons & Quinn (2014) note, the interconnection between relevant multi-disciplinary STEM learning and teaching and the future skills and knowledge requirements of industry must be enhanced. More than ever before, STEM academics have a crucial role to play in preparing students for the global economy and the workforce of the future. Building and expanding STEM multi-disciplinary capacity in academic staff and integrating it into all STEM discipline curriculum is integral to this preparation.

Why Rock the STEM Boat?

Educational trends in the learning and teaching of STEM disciplines increasingly focus upon the need for multi-disciplinary industry-related approaches to student learning, that maximise opportunities for future employment and lifelong learning (Kuenzi, 2008; OECD, 2014). There is evidence that best practice approaches to STEM learning and teaching ensure that students not only acquire knowledge, but also learn how to apply and adapt this knowledge to a variety of contexts (OCS, 2014). However in the Australian tertiary sector, STEM learning and teaching remains, for the most part, discipline-content entrenched. Rice (2011) notes that STEM disciplines in tertiary education are taught through "paradigmatic discipline-based examples" which are not practical, nor reflective of real-life industry problems. STEM disciplines are seen as opportunities to induct students into the content of the discipline, not as opportunities to develop multi-disciplinary skills or develop solutions to complex future problems. Efforts by STEM academics to undertake multi-disciplinary industry projects are rare and often not sustained. Silos of best practice multi-disciplinary projects remain at the fringes of the curriculum , often in the "project, competition or challenge" arena, and are not capitalised upon at the institutional level or at the national level for the benefit of other tertiary STEM students and staff. Research indicates that successful dissemination of STEM multi-disciplinary projects depends not only upon STEM teachers' commitment to the projects, but also upon institutional support and leadership in the provision of opportunities (Clark & Ernst, 2007).

Currently the ability of STEM academic staff to engage in ongoing multi-disciplinary learning and teaching practice is compromised by skill shortages, lack of confidence, rapid technological change, lack of role-modelling by experienced academics and the discipline-specific learning and teaching demands of tertiary structures (OCS, 2014;Tytler, 2007). This results in STEM academics and their work-integrated projects in tertiary institutions offered in isolation of each other with STEM multi-disciplinary learning and teaching ad-hoc and not formally organised or often not embedded at the institutional level. Previous Australian Learning and Teaching Council (OLT) work on STEM discipline models and assessment identified that effective mechanisms for sharing practice are not readily available, and that whilst discipline-specific professional bodies all make worthy contributions, new measures to support leadership should be available (Rice, 2011).

Increasingly the needs of employers and future work opportunities do not recognise boundaries of discipline-specific education. Preparing students for new ways of dealing with growing bodies of knowledge that no longer fit neatly into a discipline programme creates enormous challenges for tertiary institutions organized along strict STEM discipline lines. Australia now ranks 81st of OECD developed countries as a converter of raw innovation capability into the outputs that future businesses need (Aust Gov, 2014). Global industries require individuals with skills and knowledge across a range of STEM disciplines. The evidence shows that high performing countries in terms of STEM advances have a reliable pipeline of STEM graduates, whose multi-disciplinary skills are valued by employers (Aus Gov, 2014). Providing only access to STEM discipline-entrenched tertiary learning is limiting options for future graduates.

Finally, the commonality of threshold learning outcomes across STEM disciplines alongside the growing industry requirements for such skills and knowledge creates a compelling need (Office of the Chief Scientist, 2012). Threshold learning outcomes in STEM disciplines reflect a high degree of skills and knowledge commonality that complements and demands multi-disciplinary approaches.

Uncharted waters.

However embedding such multidisciplinary approaches in STEM learning into core undergraduate STEM discipline curricula is for most universities "uncharted water." Whilst there is some emerging research that documents the positive effects of multi-disciplinary approaches among STEM disciplines upon the students' achievement, satisfaction and employability (Pang & Good, 2000), the understanding of the need and emphasis lacks traction in Australian universities. The employment of integrated approaches in teaching STEM disciplines using various methodologies has been outlined by Pang & Good, (2000) with significant positive results. There is also sound pedagogy behind inter or multidisciplinary courses, with advocates finding that such courses capture students' intellectual interest (Lattuca et al. 2004), prepare students for work by developing higher-order cognitive skills (Kavanagh, 2011), and increase students' tolerance for ambiguity, sensitivity to ethical issues, and creativity (Newell 1994).

But as Zubrowski (2002) notes, although research on the integrative learning and teaching approaches amongst STEM disciplines has grown, there are still a number of serious practical challenges to engaging multi-disciplinary best practice. STEM academics and their implementation of learning and teaching multi-disciplinary projects depends greatly on their perceptions of the advantages of a multi-disciplinary approach, the organisational context and the leadership and support received in their teaching environment (Sahin, 2006). That is, the decision by STEM academics to implement multi-disciplinary learning and teaching approaches to improve student outcomes and engagement is heavily dependent upon leadership support and role-modelling of such practice.

This paper discusses two multi-disciplinary STEM courses which involved students from a range of AQF levels, diverse disciplines and staff capacities. The research was developed out of the OLT funded STEM Ecosystem Project, a joint initiative between the OLT, RMIT, University of Sydney, University of Southern Queensland and University Queensland. The project was in line with the Australian Government's agenda for increased participation in tertiary education (DEEWR, 2011), increased emphasis on the relationship between education and workplaces of the future (DEEWR, 2011) and a focus upon STEM common skills as a key to national productivity and international competitiveness (Office of the Chief Scientist, 2012).

The rationale the project was based upon the four key imperatives discussed above:

- the critical industry need for STEM graduates who can demonstrate multi-disciplinary application of their skills for future global workplaces;
- the significance and importance of providing a structure for building capacity in STEM academics in multi-disciplinary teaching;
- the commonality of threshold learning outcomes across STEM disciplines; and
- the pedagogical need to encourage STEM academics to design and develop integrated, multi-disciplinary approaches to learning and teaching in industry-driven projects that focus upon future global issues.

The following section describes the two courses conducted in 2014 at RMIT University, which addressed these imperatives and delineated a framework for multi-disciplinary industry-led learning in STEM.

Building a Better STEM Boat-The Water Innovation Challenge.

More than 3.4 million people die each year from water, sanitation and hygiene-related causes. Nearly all deaths, 99 percent, occur in the developing world. Lack of access to clean water and sanitation kills those most vulnerable in the third world and indigenous communities, especially children. With 780 million people worldwide lacking access to an improved water source (or approximately one in nine people in world), STEM leadership in innovation, design and multi-disciplinary skills are urgently required to present economical, viable community-based solutions. The two courses conducted at RMIT in 2014- Water Innovation Challenges- were centred upon this need.

The Water Innovation Challenges (WIC) created opportunities for staff and students from six diverse disciplines to nominate themselves to work alongside industry mentors in a multi-skilled team to design, build and present innovative water sanitation solutions for both a Bangladesh community and an indigenous Australian community. The semester one course was conducted intensively over an eight week period to address water filtration issues in a Bangladesh community and the semester two course was conducted over a ten week period to seek water maintenance solutions for a remote indigenous community in Australia. The client for semester one was Health Habitat, a global NGO. The client for semester two, the indigenous remote N.T. community, was Sunrise Health. The semester one client was also supported by the Worldskills Foundation, which used the project to showcase the importance of global STEM water issues and multi-skilled approaches to solutions.

Invitations were circulated to all STEM students across all disciplines and across AQF levels 3-7 at RMIT through programme directors, briefly outlining the two courses and the "challenges" requiring solutions. Over 60 students were interviewed and 52 were selected, with a total of 12 students undertaking the semester one course and 40 students undertaking the course in semester two. The variance in numbers was due to key factors such as enrolment deadlines, promotion by programme directors and growth in student interest in the second course. In first semester a number of the students undertook the course as additional to their discipline programme and negotiated assessment and credit within their own core programmes upon completion of the project. The lead time for semester two allowed all students to be enrolled in the course as either an elective or a core course of their discipline programmes. Students undertaking the courses in both semesters represented the following disciplines:

- Engineering (systems; civil and environmental)
- Health science
- Plumbing
- Nursing
- Media
- Graphics

Staff involved in the courses/courses represented engineering, health, plumbing, media and IT disciplines. All students were given the same challenge:

- To realise a viable water sanitation solution for a Bangladesh or a remote indigenous community,
- To meet client needs in tender documentation (CAD, Budgeting, solutions etc), presentation and sustainability, and
- To showcase the STEM Ecosystem challenges and global opportunities emerging from the projects.

Scehduled sessions were organised around themes of the challenge (local resources, CAD, public health, costings etc) and students worked in groups with each discipline represented in each group. Session times were flexible. Students and staff were self-engaged in the learning journey. Smaller teams/subsets of the project team were formed, reformed and disbanded as the challenge scope demanded. Although a formal meeting time and place once a week was set, attendance was not compulsory. There was flexible participation in the learning with new staff and post-graduate students joining the group as skill needs dictated e.g. editors, writers, cartoonist, CAD operators.

Social media was used as a communication and document control tool. A Google site, Facebook page and drop box were used as a virtual "meeting place" and "exchange". Evaluation and feedback was built into the learning process, with set time devoted each week to evaluation of the design and development processes.

Milestones were created by the groups. These milestones formed the assessment for the courses, with reflective journals and final documentation/solution to client forming most of the assessment. Academic staff acted as a resource and organised industry speakers and other sources of information. Students worked on self-arranged themes and met with the clients or their representatives a number of times (including skype) over the semester. All students completed the tender to presentation stage. In the semester one course, four of the students were selected from the total group to present the final tender and sanitation solution to Health Habitat (the NGO client) at the Singapore Water Expo, as part of a Worldskills Challenge against a team of students from the USA. In semester two, eight of the students (two groups) travelled to Perth to present and showcase their solutions at a national student skills competition.

Students in these courses were surveyed and a smaller number (11) participated in semi-structured interviews asking them to elaborate on the survey questions. The collection of this data took place at the end of the courses each semester. Their interview responses and their answers to the written survey were recorded. In the three survey questions, participants were asked to respond with "yes", "no' or "don't know". Table 1 (below) shows a summary of the survey responses.

Table 1: Student responses to survey questions*

Survey Question	Yes	No	Don't Know
Did you like working with students from different disciplines and levels of study?	85%	10%	5%
Did you think that this course has prepared you for work once you graduate?	76%	0%	24%
Would you undertake similar types of multi-disciplinary course in the future?	81%	0%	19%

*(response rate: 67%; n=30)

In addition students completed the traditional sector analysis tool- Course Experience Surveys (CES). The data indicated a response rate of 67% with 92% of the students satisfied with the quality of the course, a Good Teaching score for the course rating 81% and Overall Satisfaction Index at 92%.

Navigating the learning- not teaching.

These two RMIT courses which formed part of the OLT-funded STEM Ecosystem project identified new skills and knowledge for the students involved and new approaches to STEM learning and teaching for the academic staff. These courses were distinctively innovative in the approaches to learning and teaching and the development of STEM graduates for the future. The first distinction lies in bringing together a multidisciplinary STEM cohort from a range of AQF levels (3-7) to examine the problem from new perspectives, to value the skills of others and to utilise the learning of others in solving new problems. As identified earlier in the paper, the critical need for tertiary students to work in multi-disciplinary teams and explore the interconnection between future skills and knowledge requirements of industry must be enhanced (Lyons, Quinn, 2014). In these courses students were provided with this opportunity. As one student responded: "It allowed me to develop and work in an environment that would reflect the real world" and from another:" I have learnt so much about working with others in a team project."

Thus the WIC courses directly enhanced the concept for students of a multi-disciplinary approach to STEM solutions. This was evidenced by their comments at interview: "I like to learn from people from other fields to expand my knowledge and maybe change my view of things."Another student responded with, "It's much more closely aligned to how industry operates, which is something that is not often addressed in normal studies."

This understanding of the need for new knowledge and multi-disciplinary team approaches was readily embraced by nearly all the students:

> "The team itself included individuals of diverse experience and background. This provided a simulation of how engineering problems are faced in the real world. The experience was invaluable."

Another student commented that:

> "A variety of different knowledge backgrounds allowed the team to understand situations from different perspectives."

These courses were distinctive in that they also provided learning opportunities for both HE and VE students within the one STEM team. In the student surveys when asked "*Did you like working with students from different disciplines and levels of study,"* 85% of the respondents said that they liked working with students from different disciplines and levels of study. This satisfaction level mirrors earlier findings by researchers into the value of integratedapproaches in teaching STEM students (Pang & Good, 2000; Kavanagh, 2011).

It is worth noting that not all students were comfortable with being in a multi-disciplinary team. Although only 10% responded negatively to this question, it highlights the many challenges working in multi-disciplinary teams. These include creating a suitable learning environment, differences in discipline approaches to problem-solving, different levels of commencing knowledge and communication across the team. Some students described how working in a STEM team was a personal challenge, and they felt uncomfortable with the learning approach. Student comments outline these challenges:"It was OK but it was hard co-ordinating people from different courses, and I didn't like it."And: "It took me by surprise. A lot of it was left up to us to understand….we had to make sense of what was happening."

This "uncomfortableness" with the learning approach and the challenge of multi-disciplinary team members, is one that can be overcome , as students grow towards an understanding of their role in a STEM team and their ability to contribute. As Kavanagh & Cokley (2011) note, the communication of potential hurdles and team challenges can solve much initial student wariness, but the importance of acquiring new skills in multi-disciplinary understandings should not be drowned out by such challenges.

The second distinction was the demonstration of STEM distributed leadership in a multidisciplinary team setting. This was achieved by creating a learning environment for the students that was characterised by role-modelling and real life learning. The WIC courses over both semesters were reliant upon collaboration and the contribution of the total project team. As a result there was no "designated" leader, but a model of distributed leadership that developed skills and capacity in the students. When asked if students had felt they had opportunities to lead sections of the design or development, the responses from the students indicated this developing capacity:

> It was a steep learning curve for me- not all are from my field, so I didn't know how to deal with that at first, but in the end I was really confident working & leading.

Other students demonstrated their desire to "extend themselves beyond their comfort zone" and place themselves in situations where they were "forced" to lead:

> This project has really prepared me for work. I had to exhibit leadership, time management skills and most of all, incorporate client requirements into our design

As the Office of the Chief Scientist (2014) notes, the need for STEM leadership is urgent and critical. By providing students with models of distributed leadership in the WIC courses, opportunities for new skills and lasting leadership qualities were built.

A third distinction in these courses was that the STEM academic staff engaged with the students as professional peers, collaborating on activities . This is in contrast to many approaches in STEM disciplines which are traditionally seen as opportunities to induct students into the content of the discipline, not as opportunities to develop solutions to complex multi-disciplinary problems (Rice, 2011). In the WIC courses, the collaboration was not "teaching" but more closely resembled a face-to-face dialogue between two sets of learners each prepared to teach the other something new. This approach resulted in STEM staff and students at all stages of experience and knowledge entering 'into a co-learning relationship guided by action and reflection' (Huesca 2003). One student commented: "It was certainly different, and effective, we always discuss ideas and share knowledge with others"

A further distinction was that the challenges were *real* global issues, along with the clients. The purpose and objectives of the WIC courses were clear to all and students involved. The students commented upon this understanding of purpose, illustrating their understanding and knowledge of the design/tender/presentation processes involved in real-world projects:

> One of the most significant opportunities that this unit has given me to this point is the chance to use my skills learnt thus far in designing and implementing a solution to a real-world problem in indigenous community.

Through the real-world problems and clients students were able to access, filter and critically engage with new STEM knowledge and new ways of knowing. When surveyed with the question: *Did you think that this course has prepared you for work once you graduate,* 76% or three quarters of the students believed that the course had prepared them for work upon graduation. Students commented that: "It showed me how to work effectively in a team for a real-world project" and:

> Most employers require the demonstration of working in teams. The exposure to a variety of disciplines and skill levels is much more reflective of the workplace and as such I feel it was highly valuable.

On the issue of the teamwork approach to solving a real- world problem, one student commented:

> It educated me in the many ways to tackle engineering problems giving me a variety of tools for development and analysis of engineering solutions that I was previously unaware of.

The WIC courses were an example of educational leadership for staff as well, as it nurtured and created confidence across staff from a range of disciplines, including early career academics. This impact upon staff was intentional – a key element of the OLT-funded STEM Ecosystem is the nurturing of academics through projects and developing opportunities for them to lead in multi-disciplinary STEM arenas. This was achieved as the comments from staff involved in the project indicate: "I learned a lot from this – it was wonderful to watch the students learn and grow. (Staff member, engineering) and:

> Without being exposed to these new experiences or being out of my comfort zone I don't think that it's possible for me to develop personally or professionally (VE plumbing teacher)

Much of current discipline-entrenched STEM learning and teaching has not equipped tertiary students in these courses to adequately tackle global problems requiring multi-disciplinary solutions. All of the students, both in the surveys and the interviews, noted their lack of discipline preparation in working in a multi-disciplinary team and their lack of ability to move beyond their discipline boundaries to solve problems and to apply knowledge in new ways. They indicated that their discipline group work had not prepared them well for the challenges of working with people from diverse industries. However all of the students surveyed enjoyed the courses as an engaging experience and over three-quarters of them felt they learnt more through involvement with other disciplines. Of concern was the fact that all of the students involved in these courses felt that multi-disciplinary work for real clients was unique in their education to date in the university. The skills gained through multi-disciplinary teamwork and meeting real client deadlines and expectations were the most obvious of skills and knowledge identified by the students. The lack of previous work of this nature by students from all the discipline areas involved in these courses, indicates our efforts to navigate students through STEM tertiary education and equip them with lifelong learning skills may be failing.

As with all action research studies there are limitations to the results. Firstly, this research has only examined the outcomes from two courses at one university. In addition, the sample sizes in these courses were very small due to the nature of both courses. Participating students may not be representative of students in other educational institutions. Consequently, generalising findings to other student groups should be done cautiously. Although the second semester course was a core component of engineering programmes, it was an elective for all other discipline students, similarly with the first semester course, so the cohort did consist of a large number of students who had elected to be there.

A second limitation relates to the duration of the projects, as well as to students' overall experience as learners in a higher education setting. Whilst there were some final year students involved, there were also a number of first year students. When the students were surveyed and asked if they felt they had learnt valuable work skills for the future, 24% of them were undecided and responded "don't know" to the survey question. Those who clarified their response typically said that it was too early in their university programme to have a sense of graduation benefits. For example one student commented that: "It has definitely been beneficial in simulating real-world experiences, however first year is a little too soon to tell." The staff involved also spanned a wide range of experience and industry knowledge, which may have influenced the project outcomes.

Finally the sustainability of such lifelong learning is the challenge for STEM multidisciplinary approaches.The WIC has resulted in significant impacts within the university, the sector, the government and the international community. However, future leadership will involve greater STEM inter-discipline co-operation and senior recognition and support of these approaches in tertiary institutions. The irony is that for many of the STEM students involved in these courses, they already understand this need, with 81% of them responding positively to the question of future multi-disciplinary study. As one student summed it up: "I would take classes like this again because it is so interesting and useful for the future."

It is the very limitations discussed above that may provide avenues for future research such as the broader involvement of wider ranges of disciplines, the broadening of the student diversity and the embedding or sustainability of these courses over time. Finally there may be opportunities to explore future employment patterns of students undertaking multi-disciplinary STEM courses and their career pathways. Such research would provide valuable windows into the STEM lifelong learning boat.

Conclusion

> STEM disciplines are critical engines of innovation and growth. The future of the Australian economy will be underpinned by the number and calibre of STEM graduates and the academic staff leading them. We are at present falling short: something different has to be done, demanding a paradigm shift" (Office of the Chief Scientist, 2012)

If Australia is to be a productive and progressive economy in the future, a workforce of scientifically and technologically literate people is required. With identified shortages across the engineering, science and technology professions, there is also a growing need for a highly trained pool of academic staff who can, through learning and teaching initiatives, impart not only their own discipline but create multi-disciplinary STEM opportunities for the current students who will go on to workplaces of the future. With rapid technological change in industry, it is likely that skills demanded in the future will differ from those required in the past (Loble, 2005).

Expanding student options and providing work-relevant multi-disciplinary learning and teaching in STEM is fundamental to meeting Australia's future STEM needs, as well as providing social and individual satisfaction. The development of capacity and senior leadership that nurtures and creates collaboration across STEM disciplines and fosters and grows confidence amongst STEM academic staff in promoting these multi-disciplinary projects and curricula is also required for the sustainability of these approaches.

This project involved only a small number of students and staff from the lead university- this is an obvious limitation. Further multidisciplinary courses of the OLT STEM Ecosystem project are being conducted at the partner universities as the project progresses.However, it is evident from this small study that student skills in STEM multi-disciplinary teams, communication and problem-solving can be developed and nurtured. There is also an urgent need to develop undergraduate skills in applying the interconnectedness of STEM knowledge across disciplines. Doing this will necessiate a change of thinking about the value and curriculum place of multi-disciplinary, global approaches to learning and teaching in STEM disciplines. Only then can we be sure that our students are on the right boat!

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