STE(A)M Education for Southeast Asia

Riccardo Corrado and Patchanee Tungjan

INTRODUCTION: STEM IN THE SOUTHEAST ASIAN CONTEXT

The history of the acronym STEM (Science, Technology, Engineering, and Mathematics) started at the beginning of the last decade of the past century. The acronym was originally written as SMET (Science, Mathematics, Engineering, and Technology), before then being changed due to phonetic reasons to the well-known STEM.[1] The STEM movement gained momentum in the next decade, in 2005, when Virginia Tech University created a degree in STEM education.[2] STEM not only includes those disciplines commonly considered under the umbrella of STEM, such as physics, chemistry, and mathematics, but also includes disciplines in psychology and social sciences, such as political science, and economics.[3] Since 2005, many calls for enhancing STEM education have been voiced out, mostly from employers concerned about the lack of workplace-skilled professionals capable of answering the increasing demand for skilled labour from those companies, mostly related to

1. Martín-Páez, Tobías, David Aguilera, Francisco Javier Perales-Palacios, and José Miguel Vílchez-González. 2019. What are we talking about when we talk about STEM education? A review of literature. Science Education 103. (https://doi.org/https://doi.org/10.1002/sce.21522).

2. Martín-Páez, Tobías, Aguilera, David, Perales-Palacios, Francisco Javier and Vílchez-González, José Miguel. 2019. Science Education 103. (https://doi.org/https://doi.org/10.1002/sce.21522).

3. Li, Yeping, Ke Wang, Yu Xiao, and Jeffrey E. Froyd. 2020. Research and trends in STEM education: a systematic review of journal publications. International Journal of STEM Education 7. (https://doi.org/10.1186/s40594-020-00207-6).

innovation.[4] Today, there is no unique agreed definition of STEM education,[5] but one aspect to surely emerge is the transdisciplinary aspect of it, mostly when focusing on STEM integration in learning activities.[6]

With a focus on the Southeast Asian ecosystem, and to promote regional cooperation in education, science, and culture in the region, in 1965 the Southeast Asian Ministers of Education Organisation (SEAMEO) was established by (using the current names) Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. SEAMEO is a regional intergovernmental organisation that "maintains its work and aspirations for development with peoples of the region to make lives better in quality and equity in education, preventive health education, culture and tradition, information and communication technology, languages, poverty alleviation and agriculture, and natural resources".[7] Additionally, within SEAMEO, the SEAMEO STEM Education (STEM-ED) Centre started operations in 2019 and has since begun its mission of uplifting the capacity and capabilities of STEM education in the region,[8] pinpointing three main goals: (1) improving science and mathematics performance for students, benchmarking the improvement with the PISA scores, (2) shifting from a resource-intensive to a more balanced paradigm of development, and, finally, (3) attracting and obtaining science and technology expertise to escape the middle-income trap, leveraging on skills and equipment upgrading across the region.[9]

When focusing on the definition given by SEAMEO to STEM education, the current STEM-ED Centre's definition of it is: "a teaching and learning approach, which emphasises the connections among or the integration of knowledge and skills in science, technology, engineering, and mathematics to address problems facing our communities as well as larger global issues that require a skilled workforce and knowledgeable citizens who can apply these skills and knowledge to develop

4. Falloon, Garry, Maria Hatzigianni, Matt Bower, Anne Forbes, and Michael Stevenson. 2020. Understanding K-12 STEM Education: a Framework for Developing STEM Literacy. Journal of Science Education and Technology 29. (https://doi.org/10.1007/s10956-020-09823-x).

5. Falloon, Garry, Hatzigianni, Maria, Bower, Matt, Forbes, Anne and Stevenson, Michael. 2020. Journal of Science Education and Technology 29. (https://doi.org/10.1007/s10956-020-09823-x).

6. Takeuchi, Miwa A., Pratim Sengupta, Marie-Claire Shanahan, Jennifer D. Adams, and Maryam Hachem. 2020. Transdisciplinarity in STEM education: a critical review. Studies in Science Education 56. (https://doi.org/10.1080/03057267.2020.1755802).

7. SEAMEO. 2020. What is SEAMEO? SEAMEO STEM-ED Reports. (https://seameo-stemed.org/about/centre-profile).

8. SEAMEO. 2020. SEAMEO STEM-ED Reports.

9. SEAMEO. 2020. SEAMEO STEM-ED Reports.

solutions".[10] To evaluate the standards for STEM education, the STEM-ED Centre also introduced five indicators identifying what learners should know and be able to do, thus representing de facto learner learning levels and development processes.[11] Specifically, the five indicators are the following:

1. Identifying the problem.
2. Collecting data and ideas relevant to the problem.
3. Designing potential solutions by applying STEM knowledge and practical engineering methods.
4. Testing, assessing, and improving solution(s).
5. Presenting problem-solving methods and solution(s).

Furthermore, several review studies have highlighted that while STEM education in Asia began in 2013,[12] it has not been developed in a homogeneous way across regional countries, with, for example, Malaysia, Singapore, Thailand, and the Philippines having already implemented STEM in their curriculum, while others are still lagging behind.[13] Thus, accounting for this non-homogeneous STEM education ecosystem in the Southeast Asian context, in the following of this chapter, an overview of the current scenario is offered.

SOUTHEAST ASIA: A NON-HOMOGENEOUS ECOSYSTEM

Southeast Asia is a very diverse region, with a non-homogeneous regional digital divide issue which appears to be larger when compared to the rest of the world,[14] and with roots that can be found in the educational background. In this context, STEM education has attracted significant interest, in some countries more than

10. SEAMEO STEM-ED. 2020. STEM Education Standards SEAMEO Regional STEM Education Center. (https://drive.google.com/file/d/1Mh83obK1CK73SvIDFVf9R3q3m1xGExjq/view).

11. SEAMEO STEM-ED. 2020.

12. Wahono, Bevo, Pei-Ling Lin, and Chun-Yen Chang. 2020. Evidence of STEM enactment effectiveness in Asian student learning outcomes. International Journal of STEM Education 7. (https://doi.org/10.1186/s40594-020-00236-1).

13. Wahono, Bevo, Lin, Pei-Ling and Chang, Chun-Yen. 2020. International Journal of STEM Education 7. (https://doi.org/10.1186/s40594-020-00236-1).

14. Corrado, Riccardo, and Audrey Liwan. 2021. E-Learning: Global Perspectives, Challenges and Educational Implications. In: Education in a Competitive and Globalizing World, edited by Donnie Adams, and Chuah Kee Man, 125-148. NY, USA: Nova Science Publishers. (https://doi.org/10.52305/QGNZ7440).

others, in parallel with the technological pervasion of the educational ecosystem across the region.[15]

For Malaysia, from 1957, after its independence, the country has experienced a remarkable improvement in the education sector, with increased spending that saw, in 2011, the country recording one of the highest educational expenditures (related to GDP) in the world.[16] The importance of STEM is not something new in Malaysia, with its government having emphasised the importance of science and technology since the 1970s.[17] In 2013, the Ministry of Education introduced the Malaysia Education Blueprint 2013-2025, defining three waves. The first one, ranging from 2013 to 2015, had the main goal of turning around the system by supporting teachers and focusing on core skills.[18] The second wave, from 2016 to 2020, had the goal of accelerating system improvements such as curriculum, English language exposure, Information Communications Technology (ICT) innovations, competency, and performance-based progression and international accreditations.[19] Finally, the current wave, from 2021 to 2025, focuses on moving toward excellence with increased operational flexibility, aiming to scale up innovation, cultivate professional excellence, and review school structure.[20] With this blueprint, the Ministry of Education implemented various strategies to strengthen the STEM-related subjects, aiming to boost the production and preparation of skilled professionals, and identified three main goals: (1) raising student interest through new learning approaches and adopting an enhanced curriculum, (2) sharpening the skills and abilities of teachers, and (3) building public and student awareness using national campaigns. The idea underpinning the vision to change the existing curriculum to the Standard Secondary School Curriculum (SSSC) was to make

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15. Corrado, Riccardo and Liwan, Audrey 2021. Education in a Competitive and Globalizing World (https://doi.org/10.52305/QGNZ7440).

16. MOE. 2013. Malaysia Education Blueprint 2013-2025. Putrajaya, Malaysia: Kementerian Pendidikan Malaysia. (https://www.moe.gov.my/muat-turun/penerbitan-dan-jurnal/dasar/1207-malaysia-education-blueprint-2013-2025/file).

17. Kaur, Anisha Haveena, Sharmini Gopinathan, and Murail Raman. 2020. Work-in-Progress—Role of Innovative Teaching Strategies in Enhancing STEM Education in Malaysia. In: 6th International Conference of the Immersive Learning Research Network (iLRN). (https://doi.org/10.23919/iLRN47897.2020.9155174).

18. MOE. 2013.

19. MOE. 2013.

20. MOE. 2013.

STEM learning practices one of the pillars of the education system of Malaysia.[21] At the Virtual Kuala Lumpur Engineering Science Fair 2021 (e-KLESF 2021), an event supported by the Ministry of Education, the Academy of Sciences Malaysia (ASM), the Associated Chinese Chambers of Commerce and Industry of Malaysia (ACCCIM), and the Malaysian Institute of Physics (IFM), the Ministry of Education highlighted how various programmes and activities have been carried out in recent years in the country aimed at enhancing not only the interest of students but also the competence of teachers in STEM,[22] as well as changes in the curriculum, such as at the secondary school level, from the Integrated Curriculum for Secondary Schools (KBSM) to the Standard Curriculum for Secondary Schools (KSSM).[23] Additionally, campaigns have been organised and carried out in collaboration with government agencies, the private sector, and non-governmental organisations (NGO) to raise awareness of STEM-related opportunities, and educate both students and the general public about the wide spectrum of career opportunities in STEM disciplines.[24] Yet, despite initiatives undertaken by the Ministry of Education and the Ministry of Science, Technology, and Innovation (MOSTI) in Malaysia, the country is experiencing a steady decline in the number of students enrolling in STEM majors in tertiary education,[25] with the proportion of students enrolling in STEM-related majors having dropped from 48 per cent in 2012 to 44 per cent in 2017.[26]

Regarding Singapore, currently, there are many schools offering STEM education. Already in 2014, the Singaporean Ministry of Education had set up a partnership with Stem Inc, a unit established in January 2014 under Science Centre

21. Razali, Fazilah, Umi Kalthom Abdul Manaf, and Ahmad Fauzi Mohd Ayub. 2020. STEM Education in Malaysia towards Developing a Human Capital through Motivating Science Subject. International Journal of Learning, Teaching and Educational Research 19. (https://doi.org/10.26803/ijlter.19.5.25).

22. The Star. 2021. Sparking STEM interest in schools. (https://www.thestar.com.my/news/education/2021/11/14/sparking-stem-interest-in-schools).

23. Kong, Suik F., and Mohd E. Mohd Matore. 2022. Can a Science, Technology, Engineering, and Mathematics (STEM) Approach Enhance Students' Mathematics Performance? Sustainability 14. (https://doi.org/10.3390/su14010379).

24. SAMEO. 2020. Why STEM - 21st Century Skills in Southeast Asia's Education System. Seadstem: Southeast Asian Digital STEM Platform. (https://www.seameo-innotech.org/wp-content/uploads/2020/03/SEADSTEM-Project-Description-2019-2020_Short.pdf).

25. Palpanadan, Sarala Thulasi and Venosha Ravana. 2022. Future Trajectories in Teaching-Learning Practices for STEM Education in Malaysian Secondary Schools: A Scoping Review. Asia Proceedings of Social Sciences 9. (https://doi.org/10.31580/apss.v9i1.2273).

26. Kaur, Anisha Haveena, Gopinathan, Sharmini and Raman, Murail. 2020. 6th International Conference of the Immersive Learning Research Network (iLRN). (https://doi.org/10.23919/iLRN47897.2020.9155174).

Singapore (SCS), to support the flourishing of STEM learning activities.[27] Specifically, the STEM Applied Learning Programme (ALP) was idealised to foster interest in STEM and encourage students to pursue STEM-related careers, with a focus on "hands-on activities, making the relatedness between subjects explicit, encouraging learning through play as well as exploration, and the development of 21st-century competencies such as collaboration, communication, and problem-solving skills".[28] To be a school delivering STEM ALP programmes, a school had to submit a proposal for joint review by the Singaporean Ministry of Education and SCS, and then participate in a sharing session with both the bodies (the Singaporean Ministry of Education and SCS), involving the key personnel who would implement the STEM ALP, such as the principal and senior management.[29] The selected STEM educators, appointed for two and a half years in their position, had to provide on-site support, including conducting professional development workshops for teachers, technical guidance, and assistance in lessons delivery.[30] Additionally, STEM education was included in the curriculum, with approximately 20 hours of STEM ALP lessons for weekly delivery over a semester, with the first semester lasting 21 weeks, and the second one lasting 24.[31] Additional schools also partnered with other institutions. Examples include EtonHouse International School Singapore, XCL World Academy Singapore and Dover Court International School. The EtonHouse EdTech curriculum specifically includes programming, animation, cybersecurity, and 3D gaming as activities for students starting from kindergarten. The XCL World Academy Singapore, which has formed a partnership with Carnegie Mellon University and the CREATE Lab, is providing a clear focus on coding, Artificial Intelligence (AI), and robotics. Dover Court International School has partnered with the Massachusetts Institute of Technology (MIT), and is offering an annual visit to MIT, training for STEM teachers, and an interdisciplinary approach. These are just some of the examples of schools in Singapore providing STEM education and leveraging on international partnerships.

In the case of Thailand, STEM education was introduced in the country in 2012, at the dawn of another round of education reforms following the major one which

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27. ADB. 2021. Different Approaches to Learning Science, Technology, Engineering, and Mathematics: Case Studies from Thailand, the Republic of Korea, Singapore, and Finland. Asian Development Bank. (https://dx.doi.org/10.22617/SPR210041).

28. ADB. 2021. Asian Development Bank.

29. ADB. 2021. Asian Development Bank.

30. ADB. 2021. Asian Development Bank.

31. ADB. 2021. Asian Development Bank.

took place in 1999.[32] A series of forums for open discussion took place after the 6th Thai-US Education Roundtable at the University of Minnesota in 2012.[33] Currently, as an outgrowth of the 2012-2016 plan, the Kingdom has identified STEM education as a key feature of the education and workforce development policy.[34] Despite the country having a "solid background and infrastructure for STEM education", it can be said that Thailand does not have a unique definition of STEM.[35] Yet, currently, in the Thai ecosystem, the STEM topic has become a hot one among policymakers, academics, school teachers, science and mathematics educators, scientists, and engineers, and has quickly been adopted as a major policy by the National Science Technology and Innovation Policy Office (STI), the Institute for the Promotion of Science and Technology (IPST), the Ministry of Education, and the Ministry of Science and Technology.[36] To include STEM in formal education, IPST, together with STI and the National Economic and Social Development Board (NESDB), formulated a five-year plan (2014-2018) strategy for driving the development of STEM education in the country, including curriculum updates and teachers' professional development.[37] Currently, there are a number of schools implementing STEM programmes, such as Lamplaimat Pattana School (LPMP) in Buri Ram province, Mahidol Wittayanusorn School (MWIT), Princess's Chulabhorn Rajavidhayalai Schools, and the Science Classrooms in University-Affiliated School (SCiUS). But these institutions belong to the category of "alternative schools", which possess autonomy in administration, finance, and implementation of non-traditional teaching and learn-

32. Promboon, Sumonta, Fred N. Finley, and Kittisak Kaweekijmanee. 2018. The Evolution and Current Status of STEM Education in Thailand: Policy Directions and Recommendations. In: Education in Thailand: An Old Elephant in Search of a New Mahout, edited by Gerald W. Fry, 423-459. Singapore: Springer Singapore. (https://doi.org/10.1007/978-981-10-7857-6_17).

33. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

34. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

35. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

36. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

37. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

ing approaches, allowing them to move similarly to private schools.[38] Unlike these alternative schools, the publicly managed schools instead usually present a more resisting approach to innovation and changes. In fact, if it can be said that in the recent past, Thailand has been "highly successful in preparing top-performing students to compete in several world science and mathematics forums such as the International Mathematics and Science Olympiad", it is also essential to highlight that the vast majority of these students come from elite schools, with clearly a very large gap in overall performance compared with students from publicly managed schools.[39]

Like in Thailand, in Cambodia, there is not a unique official definition of STEM. Despite this, in the Cambodian context, there are a few private institutions leveraging on STEM education, such as E2STEM Education, a non-profit STEM education institution working with the Ministry of Education, Youth and Sport (MoEYS) in a public-private partnership, American University of Phnom Penh High School Foxcroft Academy (AUPPHS-FA), a private institution partnering with Foxcroft Academy (a private preparatory high school located in Dover-Foxcroft, US) and the Canadian International School of Phnom Penh (CIS), in addition to other private institutions in the country. Besides these private institutions, in the public sector, some actions have also been taken, with the introduction of Cambodia's New Generation Schools (NGS). The NGS was established with a new reform inaugurated by the MoEYS in 2014, with the goal of creating autonomous public schools with a mandate to innovate and improve educational quality.[40] The NGS specifically focuses on seven pillars, namely "(1) science and math achievement, (2) science and math self-efficacy, (3) science and math outcome expectations, (4) attitudes toward science, (5) interactive science and math lessons, (6) support from science and math teachers and (7) encouragement and support in science from family".[41] Yet, the effectiveness, in terms of results, of the NGS has still not been clearly investigated,

38. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

39. Promboon, Sumonta, Finley, Fred N. and Kaweekijmanee, Kittisak. 2018. Education in Thailand: An Old Elephant in Search of a New Mahout (https://doi.org/10.1007/978-981-10-7857-6_17).

40. KAPE. 2014. New Generation School (NGS). (http://www.kapekh.org/en/what-we-do/16/?pro_id=20).

41. Kao, Sovansophal. 2021. A quantitative investigation of the effects of new generation vs traditional upper secondary schools in Cambodia through the lens of STEM transfer model. International Journal of Comparative Education and Development 23. (https://doi.org/10.1108/IJCED-03-2021-0025).

and it has been pointed out that there have been both positive and negative results that have emerged from primary research on these schools.[42] Additionally, it is also important to understand that Cambodia, even if having improved in the past years, is still suffering from educational issues related to teachers' preparation and infrastructures.[43] In general, the absence of previous research work on STEM education in the Cambodian context[44] represents a gap to be filled to better drive the journey of Cambodia in terms of STEM education.

Regarding the case of Vietnam, among developing nations, the country provides an "exotic case of the relationship between social factors and STEM education with its high economic growth rates and the top position in the Programme for International Student Assessment (PISA) ranking of average scores in Math, Science, and Reading".[45] These results have been connected to the investment in lifelong education by the government, a consequence of the Vietnamese culture where lifelong studies have been historically normalised.[46] In Vietnam, STEM education and related activities have been fostered since 2012, mostly targeting high-end markets in large cities, and focusing on coding and robotics.[47] After joining the ASEAN community and the World Trade Organisation, Vietnam found itself in need of shifting to a STEM-focused curriculum in K-12 and higher education, aiming to stay competitive in the rapidly growing global economy with the global workforce demanding

42. Kao, Sovansophal. 2021. International Journal of Comparative Education and Development 23. (https://doi.org/10.1108/IJCED-03-2021-0025).

43. Corrado, Riccardo, Robert E. Flinn, and Patchanee Tungjan. 2019. Can ICT Help Cambodian Students Become the Solution for Improving Education in the Country? Journal of Management, Economics, and Industrial Organization 3. (https://doi.org/10.31039/jomeino.2019.3.2.1).

44. Ban, Chanphalla. 2020. The Current State of Cambodia's STEM Education: A Case Study of the Preah Sisowath New Generation School. Future Forum. (https://www.futureforum.asia/_files/ugd/dffd34_20532a2f6dbf41c09b30498c77f167d7.pdf).

45. Vuong, Quan Hoang, Pham Thang Hang, Trung Tran, Thu-Trang Vuong, Nguyen Manh Cuong, Nguyen P. Khanh Linh, Viet-Phuong La, and Ho Manh-Toan. 2020. STEM Education and Outcomes in Vietnam: Views from the Social Gap and Gender Issues. SSRN Electronic Journal. (https://doi.org/10.2139/ssrn.3543346).

46. Vuong, Quan Hoang, Hang, Pham Thang, Tran, Trung, Vuong, Thu-Trang, Cuong, Nguyen Manh, Linh, Nguyen P. Khanh, La, Viet-Phuong and Manh-Toan, Ho. 2020. SSRN Electronic Journal. (https://doi.org/10.2139/ssrn.3543346).

47. Nguyen, Thanh-Tung, Dieu-Linh Hoang, Hoang-Thuy Linh Nguyen, and Thanh-Binh Nguyen. 2021. STEM-Oriented activities for improving student performance in Chu Van An secondary school, Thai Nguyen province, Vietnam. Journal of Physics: Conference Series 1835. (https://doi.org/10.1088/1742-6596/1835/1/012053).

skilled professionals.[48] Considering this, STEM education has been introduced into the country through many ways and initiatives, with one of the priority lanes represented through private education companies such as STEM Academy and Creative Academy S3.[49] Successful community events such as STEM Day saw the participation of many educational institutions and high schools such as Ta Quang Buu, Trung Vuong, and Olympia.[50] Yet, many teachers and parents still have little to no exposure and awareness of STEM education, and Vietnam still has to move forward in terms of developing more STEM teachers, applying more science and technology to management, enhancing community involvement, and building, directing, and implementing the educational goals of Vietnamese schools in every stage.[51]

In the case of Indonesia, the promotion of STEM education has been set as a priority by the government.[52] The curriculum used in Indonesia is known as Curriculum 2013, and its goal was to prepare Indonesians "to live as individuals and citizens who are productive, creative, innovative, effective, and able to contribute to the life of their society, nation, state, and civilisation".[53] The 2013 curriculum was developed with a clear aim of improving students' mindset, students-centred learning, "interactive learning, network learning, active-seeking learning, individual and group learning patterns, [and] multidisciplinary learning patterns, and strengthening critical learning patterns".[54] Additionally, in recent years, Indonesia has experienced a fast increase in the interest in STEM subjects in schools.[55] At

48. Chen, Danying Janny, Anne Namatsi Lutomia, and Van Thi Hong Pham. 2021. STEM Education and STEM-Focused Career Development in Vietnam. In: Human Resource Development in Vietnam: Research and Practice, edited by Hien Thi Tran, Tam To Phuong, Huyen Thi Minh Van, Gary N. McLean, and Mark A. Ashwill, 173-198. Cham: Springer International Publishing. (https://doi.org/10.1007/978-3-030-51533-1_7).

49. Loan, Ta Thi Thanh. 2019. STEM Education in Taiwan - Lessons Learner for Vietnam. European Journal of Research and Reflection in Educational Sciences 7.

50. Loan, Ta Thi Thanh. 2019. European Journal of Research and Reflection in Educational Sciences 7.

51. Loan, Ta Thi Thanh. 2019. European Journal of Research and Reflection in Educational Sciences 7.

52. SAMEO. 2020. Seadstem: Southeast Asian Digital STEM Platform.

53. Sulaeman, Nurul, Shelly Efwinda, and Pramudya Dwi Aristya Putra. 2022. Teacher readiness in STEM education: Voices of Indonesian Physics teachers. Journal of Technology and Science Education 12. (https://doi.org/0.3926/jotse.1191).

54. Sulaeman, Nurul, Efwinda, Shelly and Putra, Pramudya Dwi Aristya. 2022. Journal of Technology and Science Education 12. (https://doi.org/0.3926/jotse.1191).

55. Nugroho, Oktian Fajar, Anna Permanasari, Harry Firman, and Riandi Riandi. 2021. The Urgency of STEM Education in Indonesia. Jurnal Penelitian Dan Pembelajaran IPA 7. (https://doi.org/10.30870/jppi.v7i2.5979).

the university level, universities that among others have focused on researching and developing STEM education are Universitas Pendidikan Indonesia, Syiah Kuala University, and Yogyakarta State University.[56] Specifically, Syiah Kuala University has built, in collaboration with an university in Malaysia, a STEM Center, while Universitas Pendidikan Indonesia is collaborating with the Indonesian government through P4TK (Pusat Pengembangan Pemberdayaan Pendidik dan Tenaga Kependidikan) and with SAMEO as a partner.[57] In the literature, there are a few research works on STEM implementation in the Indonesian context,[58] focusing on fostering students' creativity, critical thinking, causal reasoning, and engineering and technology literacy.[59] Finally, an interesting project was initiated in Indonesia to connect STEM education with the well-known issue of national disasters involving the country: STEM-D (STEM and disaster). STEM-D has been promoted as a strategy aiming to enable the integration of STEM with disaster-prevention education.[60] Through STEM-D, Indonesian students could be exposed to learning STEM-related experiences, while being prepared for natural disasters. Yet, research works have pointed out that at this stage, Indonesian science teachers have a very good level of attitude, a moderate level in application, and a poor level of knowledge regarding STEM education.[61]

Regarding the Philippines, STEM education has been a topic of interest for several years already. To illustrate this, in the past few years the Department of Education (DepEd) has already included STEM as one of the tracks of the senior high school curricula, preparing learners to take a higher education degree in any STEM-

56. Nugroho, Oktian Fajar, Anna Permanasari. Permanasari, and Harry Firman. 2019. The Movement of STEM Education in Indonesia: Science Teachers' Perspectives. Jurnal Pendidikan IPA Indonesia 8. (https://doi.org/10.15294/jpii.v8i3.19252).

57. Nugroho, Oktian Fajar, Permanasari, Anna Permanasari. and Firman, Harry. 2019. Jurnal Pendidikan IPA Indonesia 8. (https://doi.org/10.15294/jpii.v8i3.19252).

58. Permanasari, Anna. 2016. STEM Education: Inovasi dalam Pembelajaran Sains. In: Seminar Nasional Pendidikan Sains VI 2016. Sebelas Maret University. (https://www.neliti.com/publications/173124/).

59. Nugroho, Oktian Fajar, Permanasari, Anna Permanasari, and Firman, Harry. 2019. Jurnal Pendidikan IPA Indonesia 8. (https://doi.org/10.15294/jpii.v8i3.19252).

60. Sampurno, Pandu J., Yessi A. Sari, and Agusta D. Wijaya. 2015. Integrating STEM (Science, Technology, Engineering, Mathematics) and Disaster (STEM-D) Education for Building Students' Disaster Literacy. International Journal of Learning and Teaching 1. (https://doi.org/10.18178/ijlt.1.1.73-76).

61. Wahono, Bevo, and Chun-Yen Chang. 2019. Assessing Teacher's Attitude, Knowledge, and Application (AKA) on STEM: An Effort to Foster the Sustainable Development of STEM Education. Sustainability 11. (https://www.mdpi.com/2071-1050/11/4/950).

related discipline.[62] In 2019, the Center for Integrated STEM Education (CISTEM) was established by Unilab Foundation's STEM+PH in partnership with the University of the Philippines College of Education.[63] The goal of this project is to strengthen integrated STEM education "through capacity building for teachers and educational institutions, curricular innovations, maximised network linkages, and learner empowerment".[64] Additionally, in 2019, the Department of Science and Technology (DOST) Secretary, Fortunato de la Peña, and the US Ambassador to the Philippines, Sung Kim, signed an agreement on scientific and technological cooperation.[65] This agreement has been covering areas of collaboration in multiple domains, such as STEM education, marine and environmental sciences, climate change, and renewable energy.[66] This agreement proposed three main pillars, namely (1) remote scientific collaboration, (2) building relationships between their respective scientific institutions and communities, and (3) providing opportunities for capacity building and exchange of ideas.[67] It is also interesting to notice how in the Philippines context, there exists a clear interest specifically on STEAM (Science, Technology, Engineering, Arts, and Mathematics). In fact, already in 2015, the Commission on Higher Education (CHED) had initiated a strong meta-discipline revolving around STEM with the goal of strengthening the relationship of STEM with the agri-fisheries and arts fields, consequently establishing the STEAM meta-discipline in the Philippine context. Yet, similar to the Malaysian context, despite the efforts of the Filipino government, only 38.5 per cent out of the three and a half million collegiate enrolment in 2019 chose disciplines under STEAM, with a completion rate inferior to 22 per cent.[68]

62. Sarmiento, Celina P., Marie Paz E. Morales, Levi E. Elipane, and Brando C. Palomar. 2020. Assessment practices in Philippine higher STEAM education. Journal of University Teaching & Learning Practice 17. (https://doi.org/10.53761/1.17.5.18).

63. Paderna, Edwehna Elinore S., and Sheryl Lyn C. Monterola. 2021. Advancing integrated STEM education in the Philippines through STEM curriculum implementation. In: STEM Education from Asia, edited by Tang Wee Teo, Aik-Ling Tan, and Paul Teng, Routledge.

64. Paderna, Edwehna Elinore S. and Monterola, Sheryl Lyn C. 2021. STEM Education from Asia.

65. Umali, Teresa. 3 August 2019. The Philippines and U.S. sign agreement on STEM education. OpenGov Asia. (https://opengovasia.com/the-philippines-and-u-s-sign-agreement-on-stem-education/).

66. Umali, Teresa. 3 August 2019. OpenGov Asia.

67. Umali, Teresa. 3 August 2019. OpenGov Asia.

68. Sarmiento, Celina P., Morales, Marie Paz E., Elipane, Levi E. and Palomar, Brando C. 2020. Journal of University Teaching & Learning Practice 17. (https://doi.org/10.53761/1.17.5.18).

In general, it can be said that research on STEM in the Southeast Asian context is not yet uniformly flourishing across the region, and there is a clear gap in STEM research in the whole Asian context.[69] Several of the regional governments have shown curiosity first, and commitment later, in enhancing STEM education, with mixed results. Furthermore, in addition to STEM, another educational discipline is also recently gaining momentum: STEAM. But what exactly is STEAM? And more importantly, what is the difference between STEM and STEAM?

STEAM, NOT ONLY STEM

In recent years, in many educational ecosystems, a new acronym has started to emerge and is partially replacing the well-known STEM: STEAM. STEAM is an acronym that stands for Science, Technology, Engineering, Arts, and Mathematics. STEAM can be defined as "an educational discipline that aims to spark an interest and lifelong love of the arts and sciences in children from an early age",[70] aiming to prepare students to become innovators in a fast-paced changing world. The modern world requires citizens capable of mastering content across fields and disciplines while using these skills to solve ill-defined problems, typical characteristics of real-world problems, through the use of reasoning, interpretation, assumption, strategy creation, and solutions verification.[71]

Historically, STEAM emerged from STEM, with the addition of the "A" component in the acronym, standing for arts. The aim is to fuse arts, sciences, mathematics, and humanities domains through real-world modern curricula that enhance learning potentials, creative possibilities, and adaptive growth mindsets in learners.[72] This process allows the interconnecting of modelling techniques and scientific/mathematical thinking.[73] The person credited for adding arts into STEM

69. Lee, Min-Hsien, Ching Sing Chai, and Huang-Yao Hong. 2019. STEM Education in Asia Pacific: Challenges and Development. The Asia-Pacific Education Researcher 28. (https://doi.org/10.1007/s40299-018-0424-z).

70. Lathan, Joseph. 2015. Why STEAM Is so Important to 21st Century Education. (https://onlinedegrees.sandiego.edu/steam-education-in-schools/).

71. OECD. 2019. PISA 2018 Results (Volume I): What Students Know and Can Do. The OECD's Programme for International Student Assessment's (PISA) periodic testing program on student performance. (https://www.oecd-ilibrary.org/education/pisa-2018-results-volume-i_5f07c754-en).

72. Harris, Anne, and Leon R. de Bruin. 2018. Secondary school creativity, teacher practice and STEAM education: An international study. Journal of Educational Change 19. (https://doi.org/10.1007/s10833-017-9311-2).

73. Lathan, Joseph. 2015.

to generate STEAM is Georgette Yakman, an engineering and technology teacher who is considered the founding researcher of the STEAM educational framework.[74] Officially, STEAM emerged as a new pedagogy in 2007 during the Americans for the Arts-National Policy Roundtable.[75] However, the use of STEAM compared to STEM was not about just adding something new (arts) to STEM, but is more about the convergence of arts and design thinking into STEM, in an intertwining process between the "who and why" and the "what and how".[76]

Thus, what is the difference between STEM and STEAM? In comparison to STEM education, STEAM introduces the arts component, fostering the creation of more opportunities for realistic transdisciplinary learning experiences, thanks to the arts and humanity component that enables creativity in the learning process.[77] This combination of arts and STEM can produce powerful and authentic learning opportunities,[78] while fostering creativity in many aspects.[79] Specifically, creative thought processes, creative problem-solving skills, creative thinking, creative learning, and creative skills are all natural components that result from the merging process between STEM and the arts.[80] Besides creativity, collaboration is another domain that has been highlighted as benefiting from this interconnection between the arts and the STEM domain. In fact, an important component of STEAM is collaboration, which encourages and fosters creativity and innovation for learners and educators.[81] Additionally, the integration of the arts in science teaching and learning enables learning experiences characterised by opportunities for learning that are unlikely to happen in traditional knowledge-transmission science lessons.

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74. Lee, Min-Hsien, Chai, Ching Sing and Hong, Huang-Yao. 2019. The Asia-Pacific Education Researcher 28. (https://doi.org/10.1007/s40299-018-0424-z).

75. Perignat, Elaine, and Jen Katz-Buonincontro. 2019. STEAM in practice and research: An integrative literature review. Thinking Skills and Creativity 31. (https://doi.org/https://doi.org/10.1016/j.tsc.2018.10.002).

76. Lathan, Joseph. 2015.

77. Herro, Danielle, and Cassie Quigley. 2017. Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. Professional Development in Education 43. (https://doi.org/10.1080/19415257.2016.1205507).

78. Herro, Danielle, and Cassie Quigley. 2017. Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. Professional Development in Education 43. (https://doi.org/10.1080/19415257.2016.1205507).

79. Harris, Anne and de Bruin, Leon R. 2018. Journal of Educational Change 19. (https://doi.org/10.1007/s10833-017-9311-2).

80. Harris, Anne and de Bruin, Leon R. 2018. Journal of Educational Change 19. (https://doi.org/10.1007/s10833-017-9311-2).

81. Hunter-Doniger, Tracey. 2018. Art Infusion: Ideal Conditions for STEAM. Art Education 71. (https://doi.org/10.1080/00043125.2018.1414534).

CHALLENGES AHEAD

Yet for the model of STEAM education to be successful, it must be embedded in a school that not only acknowledges the rigour in the arts but also encourages creativity and innovation.[82] Collaboration is key because it allows for everyone involved to share ideas and experiences relevant to art infusion, resulting in enhanced lessons and shared knowledge.[83] Effective implementation of STEM or STEAM education is a challenge, mostly when considering developing or less-developed ecosystems. Specifically, one of the common issues that emerge from many research works is teacher preparation and professional development, starting with a shift in teaching approaches. Changes in teaching approaches are often initiated outside the classroom, resulting from research, policy debates, and administrative support within schools and districts.[84] In fact, it is not only about skills, but also beliefs and attitudes. Specifically, "beliefs about the strength of their own knowledge base and resources can aid or impede their ability to plan and execute complex lessons", and negative attitudes toward STEM education due to a lack of knowledge about STEM fields have already been identified in preschool teachers.[85] Thus, a specific campaign for helping teachers understand first, and preparing and supporting them later, is advised.[86] Furthermore, designing and implementing effective STEAM-based learning experiences in regular curricula activities represent a further challenge, mostly in specific contexts, and many barriers need to be addressed. For instance, environmental factors, school-level factors, and student-level factors have all been identified as factors to be defined and addressed for effective STEAM integration in curricula.[87]

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82. Hunter-Doniger, Tracey. 2018. Art Education 71. (https://doi.org/10.1080/00043125.2018.1414534).

83. Hunter-Doniger, Tracey. 2018. Art Education 71. (https://doi.org/10.1080/00043125.2018.1414534).

84. Jamil, Faiza M., Sandra M. Linder, and Dolores A. Stegelin. 2018. Early Childhood Teacher Beliefs About STEAM Education After a Professional Development Conference. Early Childhood Education Journal 46. (https://doi.org/10.1007/s10643-017-0875-5).

85. Jamil, Faiza M., Linder, Sandra M. and Stegelin, Dolores A. 2018. Early Childhood Education Journal 46. (https://doi.org/10.1007/s10643-017-0875-5).

86. Yıldırım, Bekir. 2021. Preschool STEM Activities: Preschool Teachers' Preparation and Views. Early Childhood Education Journal 49. (https://doi.org/10.1007/s10643-020-01056-2).

87. Kayan-Fadlelmula, Fatma, Abdellatif Sellami, Nada Abdelkader, and Salman Umer. 2022. A systematic review of STEM education research in the GCC countries: trends, gaps and barriers. International Journal of STEM Education 9. (https://doi.org/10.1186/s40594-021-00319-7).

Furthermore, when thinking about STEAM, the design of learning activities may present even further challenges. In fact, in practice, until now, the field of education has struggled to realistically blend all the disciplines into a STEAM approach,[88] nurturing the very transdisciplinary aspect of STEAM education. Additionally, when aiming for STEAM education, an impediment to it has been found across countries in the rapid and aggressive move toward more standardised testing, a process that may hinder creative collaboration, creative thinking, and in general, creativity.[89] Another impediment was identified in school curriculum restrictions, which have been described as undermining elements to effective creative practice, and interaction between educators and pupils.[90]

Thus, considering the difficulties of effective STEM and STEAM education, what guidelines should educators follow to foster it in schools, particularly when financial affordances or human resources are not available?

PBL IS A GOOD FIRST STEP

In the first instance, it is essential to remark on the concept of interdisciplinarity as a core component of STEAM. Transdisciplinarity can be defined as "going beyond the disciplines to create new knowledge or ideas".[91] Fostering connections with the community to identify real issues so that student learning experiences can be situated in meaningful contexts has been suggested to learning designers interested in implementing STEAM activities in their curricula.[92] In fact, what makes transdisciplinarity important for problem-solving is that it specifically focuses on the content of one discipline while using contexts from different ones to make the content more

88. Jolly, Anna. 2016. STEM by Design: Strategies and Activities for Grades 4–8. New York: Routledge. (https://doi.org/10.4324/9781315679976).

89. Harris, Anne and de Bruin, Leon R. 2018. Journal of Educational Change 19. (https://doi.org/10.1007/s10833-017-9311-2).

90. Harris, Anne and de Bruin, Leon R. 2018. Journal of Educational Change 19. (https://doi.org/10.1007/s10833-017-9311-2).

91. Bush, Sarah B., and Kristin L. Cook. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. In: STEAM Education: Theory and Practice, edited by Myint Swe Khine and Areepattamannil Shaljan, 19-35. Cham: Springer International Publishing. (https://doi.org/10.1007/978-3-030-04003-1_2).

92. Bush, Sarah B. and Cook, Kristin L. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. (https://doi.org/10.1007/978-3-030-04003-1_2).

relevant and inclusive.[93] This process of designing learning experiences capable of reflecting real-life challenges and situations, which are rarely confined to the artificial boundaries of a specific academic discipline,[94] needs to be fostered in the skillsets of teachers and educators, once again highlighting the fundamental aspect of professional development for teachers,[95] something that represents a real challenge for STEAM applications, mostly in developing countries.[96]

Additionally, teachers cannot be left alone in the process. Several studies pointed out that educators need several implementations and a feedback loop in order to move towards a more integrated approach in STEAM integration.[97] The boundary-crossing nature of STEAM education, when promoted by teachers, showed itself to be able to enhance students' learning and their ability to change perspectives, synthesise knowledge of different disciplines and cope with complexity,[98] through incorporating content areas by merging different subjects and exposing students to authentic scenarios with wicked challenges.[99] The arts elements included in STEAM allow it to offer students a real natural platform for transdisciplinary inquiry.[100] But the process may represent a challenge to teachers. Yet, an identified possible solution has been presented with the adoption of Project-Based Learning (PBL).

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93. Quigley, Cassie F., Dani Herro, and Abigail Baker. Moving Toward Transdisciplinary Instruction: A Longitudinal Examination of STEAM Teaching Practices. In: STEAM Education: Theory and Practice, edited by Myint Swe Khine and Shaljan Areepattamannil, 143-164. (https://doi.org/10.1007/978-3-030-04003-1_8).

94. Quigley, Cassie F., and Dani Herro. 2016. "Finding the Joy in the Unknown": Implementation of STEAM Teaching Practices in Middle School Science and Math Classrooms. Journal of Science Education and Technology 25. (https://doi.org/10.1007/s10956-016-9602-z).

95. Corrado, Riccardo, Patchanee Tungjan, and Meta Soy. 2021. Professoriate's Motivation in Cambodian Higher Education. The International Journal of Educational Organization and Leadership 28. (https://doi.org/10.18848/2329-1656/CGP/v28i02/59-74).

96. Geum, Young-Choong, and Seon-A Bae. 2012. The Recognition and Needs of Elementary School Teachers about STEAM Education. Korean Institute of Industrial Educations 37. (https://www.koreascience.or.kr/article/JAKO201232642192126.page).

97. Al Salami, Mubarak K., Carole J. Makela, and Michael A. de Miranda. 2017. Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. International Journal of Technology and Design Education 27. (https://doi.org/10.1007/s10798-015-9341-0).

98. Spelt, Elisabeth J. H., Harm J. A. Biemans, Hilde Tobi, Pieternel A. Luning, and Martin Mulder. 2009. Teaching and Learning in Interdisciplinary Higher Education: A Systematic Review. Educational Psychology Review 21. (https://doi.org/10.1007/s10648-009-9113-z).

99. Quigley, Cassie F. and Herro, Dani. 2016. Journal of Science Education and Technology 25. (https://doi.org/10.1007/s10956-016-9602-z).

100. Quigley, Cassie F. and Herro, Dani. 2016. Journal of Science Education and Technology 25. (https://doi.org/10.1007/s10956-016-9602-z).

PBL, in fact, perfectly aligns with the exploratory nature of STEAM education.[101] Explorations in STEAM PBL take time and require students to synthesise ideas and work collaboratively to solve real-world problems,[102] opening the space for collaboration also outside the classroom ecosystem, and exposing learners also to international peers.[103] Additionally, PBL also exposes students to challenges where solutions may easily fail, thus exposing them to real scenarios where failing is part of the learning path.[104] With constructivism-based teaching-learning approaches, research works have pointed out that educators who adopted this approach have later perceived their students' learning as being more enjoyable, with the learners expressing more excitement, curiosity, and motivation, compared with participating in an old-fashioned curriculum based on instructional lessons.[105] Furthermore, additional suggestions have been offered in: (1) combining STEAM teaching with the 6E learning model,[106] and with the PBL approach, (2) involving the local culture in STEAM lessons, and (3) including a substantial component of time toward application (hands-on activities), with a specific suggestion of two hours spread over two or more class periods.[107] Another suggestion for teachers is to seek support from experts outside of their content area.[108]

Furthermore, other suggestions have been identified in: (1) providing practical, on-the-go resources to help busy teachers get started in creating purpose-driven STEAM instruction; (2) allowing educators to interact deeply with the content and

101. Bush, Sarah B. and Cook, Kristin L. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. (https://doi.org/10.1007/978-3-030-04003-1_2).

102. Bush, Sarah B. and Cook, Kristin L. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. (https://doi.org/10.1007/978-3-030-04003-1_2).

103. Chen, Juebei, Anette Kolmos, and Xiangyun Du. 2021. Forms of implementation and challenges of PBL in engineering education: a review of literature. European Journal of Engineering Education 46. (https://doi.org/10.1080/03043797.2020.1718615).

104. Bush, Sarah B. and Cook, Kristin L. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. (https://doi.org/10.1007/978-3-030-04003-1_2).

105. Amo, Daniel, Paul Fox, David Fonseca, and Cesar Poyatos. 2020. Systematic Review on Which Analytics and Learning Methodologies Are Applied in Primary and Secondary Education in the Learning of Robotics Sensors. Sensors (Basel) 21. (https://doi.org/10.3390/s21010153).

106. Lin, Kuen-Yi, Hsien-Sheng Hsiao, P. John Williams, and Yu-Han Chen. 2020. Effects of 6E-oriented STEM practical activities in cultivating middle school students' attitudes toward technology and technological inquiry ability. Research in Science & Technological Education 38. (https://doi.org/10.1080/02635143.2018.1561432).

107. Wahono, Bevo, Lin, Pei-Ling and Chang, Chun-Yen. 2020. International Journal of STEM Education 7. (https://doi.org/10.1186/s40594-020-00236-1).

108. Quigley, Cassie F. and Herro, Dani. 2016. Journal of Science Education and Technology 25. (https://doi.org/10.1007/s10956-016-9602-z).

create equitable STEAM experiences that blend community and societal interests; and (3) including online companion printable resources to help educators jump-start or deepen STEAM learning throughout a school or district, supporting STEAM professional development.[109]

Finally, as a final suggestion, each country should consider the creation of a national framework to guide schools, following specific phases, in the adoption of STEAM PBL in the curricula,[110] accompanied by a monitoring and evaluation framework. Schools left alone will simply not focus on STEAM or implement it in a non-homogeneous manner, with ineffective and un-monitored approaches. A common regional framework, with national frameworks customised to each ecosystem, could support and guide the steady and effective implementation of STEAM-based learning experiences across each country, without benefiting only elite schools, and thus aggravating the already existent educational gap across countries.

CONCLUSIONS

In the past 15 years, STEM education has gained momentum across many regions of the world, transitioning in the recent years to a more holistic transdisciplinary version, named STEAM, integrating the arts in the STEM paradigm. STEM was born with the idea to prepare learners for a fast-paced changing world, hungry for skilled professionals able to answer to the growing number of companies operating across sectors, and with a specific focus on innovation. Focusing on the Southeast Asian region, the ecosystem there is presenting itself as a non-homogeneous one, with some countries like Malaysia, Thailand, Singapore, and the Philippines having already committed to enhancing STEM education, by running projects, implementing collaboration projects between the private and public sectors, and by developing schools, mainly private ones offering STEM and sometimes also STEAM programmes. On the other hand, there are other countries just now starting, like Cambodia, and other realities still behind.

STEAM, bred from the combination of arts and STEM, can produce powerful and authentic learning opportunities while fostering creativity and collaboration, all essential elements to have in the skillsets of future professionals. Effective implementation of STEAM education is not an easy process, particularly in developing

109. Bush, Sarah B. and Cook, Kristin L. 2019. Structuring STEAM Inquiries: Lessons Learned from Practice. (https://doi.org/10.1007/978-3-030-04003-1_2).

110. Amo, Daniel, Fox, Paul, Fonseca, David and Poyatos, Cesar. 2020. Sensors (Basel) 21. (https://doi.org/10.3390/s21010153).

countries. A good starting point is represented by a campaign to shift the mindset of teachers from a negative view on STEM topics, and professionally developing their skillsets to enhance their ability to create learning design activities capable of fostering collaborations among students, while supporting and unleashing creative problem-solving skills, and while being exposed to interdisciplinary learning activities. Additionally, PBL represents a possible effective approach aligned to the nature of STEAM-based learning experiences, opening the doors to experiences crossing the boundaries of the classroom. Finally, an important step to take is represented by the creation of regional and national frameworks capable of offering guidelines to schools and educators, thus guiding them in the journey for a step-by-step implementation of STEAM activities in the national curriculum across each country.

Dr. Riccardo Corrado is the Chair of the ICT programme at the American University of Phnom Penh (AUPP) and an Advisor to the Cambodian Ministry of Post and Telecommunications (MPTC). Riccardo received his bachelor's degree in Electronics Engineering and master's degree in Telecommunications Engineering from the University of Trieste, Italy. In 2012 he underwent the Italian national board exam for information engineering, organised by the Italian Ministry of Education, University and Research (MIUR), to become a professional engineer. In 2016, at the same university of his undergraduate and graduate studies, Riccardo was awarded his Ph.D. in Information Engineering, with a research focus on video and audio transmission over IEEE 802.11 ad-hoc networks. Furthermore, considering his passion for sustainable development and STEAM education, Riccardo continued his studies with a Master of Education and in 2021, he was awarded a master's degree in Education (MEd – ICT in Education) from the University of Johannesburg, South Africa, with a dissertation focused on the implementation of MOOCs in the Cambodian higher education curriculum. Riccardo's research interests involve video encoding, wireless ad hoc networking, ICT in education, and ICT for development. Currently, Riccardo is a member of the "Think Next, Act Next – The Next Gen EU-ASEAN Think Tank Dialogue" (EANGAGE), funded by the European Union, and an advisor to the STEAM Programme of the AUPP High School Foxcroft Academy (AUPPHS-FA).

Ms. Patchanee Tungjan holds a bachelor's degree and a master's degree in Occupational Therapy (OT) from Chiang Mai University, Thailand. In 2015, she became a certified occupational therapist after undergoing the Thai national board exam for OT professionals (Professional Standards for the Art of Healing in OT, issued by the OT Association of Thailand). Besides academia, Patchanee worked for almost three years as an occupational therapist in Buriram Hospital, before pursuing her graduate studies. Her current research topics are related to cognitive rehabilitation in patients affected by stroke, effects of digitalisation in the context of public health, and in general technology usage for supporting health, well-being, and education.