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# Integrating diverse robotic technologies in STEM education of Kazakhstan: a methodological approach and assessment in project-based learning

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ABSTRACT: This study provides an in-depth analysis of the integration of various robotic technologies within science, technology, engineering, mathematics (STEM) education, emphasising a project-oriented learning approach. There were 44 postgraduate students from two universities in Kazakhstan involved in this study, applying the system life cycle methodology to promote problem-solving skills. In this article are explored strategies for merging multi-Lego EV3, Arduino-Lego EV3 systems, Arduino-PC/Raspberry Pi connectivity, and computer vision libraries with Arduino in student-led projects addressing pertinent environmental issues. A comprehensive assessment framework was employed to evaluate these projects, gauging the proficiency in technological integration, practical implementation and theoretical knowledge application. The research outcomes underscore the pivotal role of such integrated systems in catalysing innovation and nurturing the next generation of STEM specialists.

## INTRODUCTION

The swift technological evolution has inflated the need for experts well-versed in science, technology, engineering and mathematics (STEM) disciplines [1][2]. As an emerging nation in Central Asia, Kazakhstan recognises STEM education's critical role and actively promotes it. In accordance with this vision, numerous Kazakh universities have collaborated with the European Erasmus+ programme to launch an innovative project on comprehensive STEM teacher education. This initiative has unfolded within a two-year Master's IT education programme, enhancing future STEM educators' knowledge and skills. Information technology (IT), a field noted for its transferable proficiencies, is prominently highlighted [3]. Integrating different robotic technologies in STEM projects is a growing area of interest, and several scholars have been focusing on this interdisciplinary approach. While teaching robotics as a standalone discipline provides a solid foundation, combining different technologies can lead to solving more significant, more complex problems.

The objectives of this research endeavour are:

- Theoretical exploration of methodologies for the amalgamation of various robotic technologies.
- Practical implementation of these methodologies in the conception and development of project work.

The first objective involves a scholarly investigation into the theoretical underpinnings of strategies that facilitate the integration of an array of robotic technologies. The second objective underscores the real-world application of these strategies, specifically in the execution and progression of project works that necessitate the fusion of diverse robotic technologies.

## LITERATURE REVIEW

Several studies have highlighted the positive impact of robotic technologies on student engagement, learning outcomes and problem-solving skills [4]. Robotic technologies provide hands-on, experiential learning opportunities that enable students to apply theoretical concepts to real-world situations, thereby fostering a deeper understanding of the subject matter [5]. Furthermore, robotic technologies encourage collaboration, communication and critical thinking skills, essential for success in the modern workforce [6].

In addition to these cognitive benefits, robotic technologies have enhanced students' motivation and interest in STEM subjects [7]. For example, Chen and Chang found that robotic technologies led to increased motivation, engagement and academic achievement in STEM courses [8]. Similarly, Benitti reviewed 40 studies on the educational potential of robotics and concluded that robotic technologies positively influenced students' attitudes toward STEM fields [9].

Various robotic technologies, including Lego EV3, Arduino and machine learning, have been employed in STEM education. Lego-based robotics, notably the Lego Mindstorms series, have been extensively used in educational settings due to their versatility, ease of use and adaptability. Studies have shown that Lego robotics can improve students' problem-solving skills, creativity and conceptual understanding [5].

Arduino, an open-source electronics platform, has also been utilised in STEM education to teach programming and electronics concepts. Arduino-based projects allow students to develop practical skills like circuit design and programming, while enhancing their understanding of core engineering principles [10].

Computer vision, a subset of artificial intelligence (AI), has been integrated into robotics education to teach students about algorithms, data analysis and predictive modelling. By incorporating computer vision in robotics projects, students can develop a more comprehensive understanding of the underlying principles of artificial intelligence and its potential applications in various domains [4].

## RESEARCH METHODOLOGY

The experimental work was carried out with a total of 44 students in the Master's degree programme of the STEM-education at two universities: the *L.N. Gumilyov* Eurasian National University in Astana and *Sarsen Amanzholov* East Kazakhstan University in Ust-Kamenogorsk, both in Kazakhstan. The participants represented diverse academic backgrounds with engineering, computer science majors and other STEM-related fields.

In this research endeavour, participants were engaged in investigative activities for an average of three hours within a single day. The instructional segments were meticulously crafted to encapsulate the integration of various robotic technologies. During practical sessions, participants were guided to select a project theme encompassing the following aspects: exploring the primary objectives set forth by the United Nations, identifying a genuine client to whom a robotic system could be proposed as a solution, and examining local news and prevailing issues. This approach was intended to foster a connection between theoretical knowledge and real-world applications, thereby enhancing the educational experience. In the context of this research, participants executed tasks adhering to the well-documented stages of the system life cycle [11]. Upon culmination, they generated a detailed report reflecting their efforts.

An educational paradigm has been established to cultivate prospective experts in information technology and STEM disciplines. The structure of this model is triadic, embodying goal-driven, content-methodological and evaluative-diagnostic constituents as shown in Figure 1.

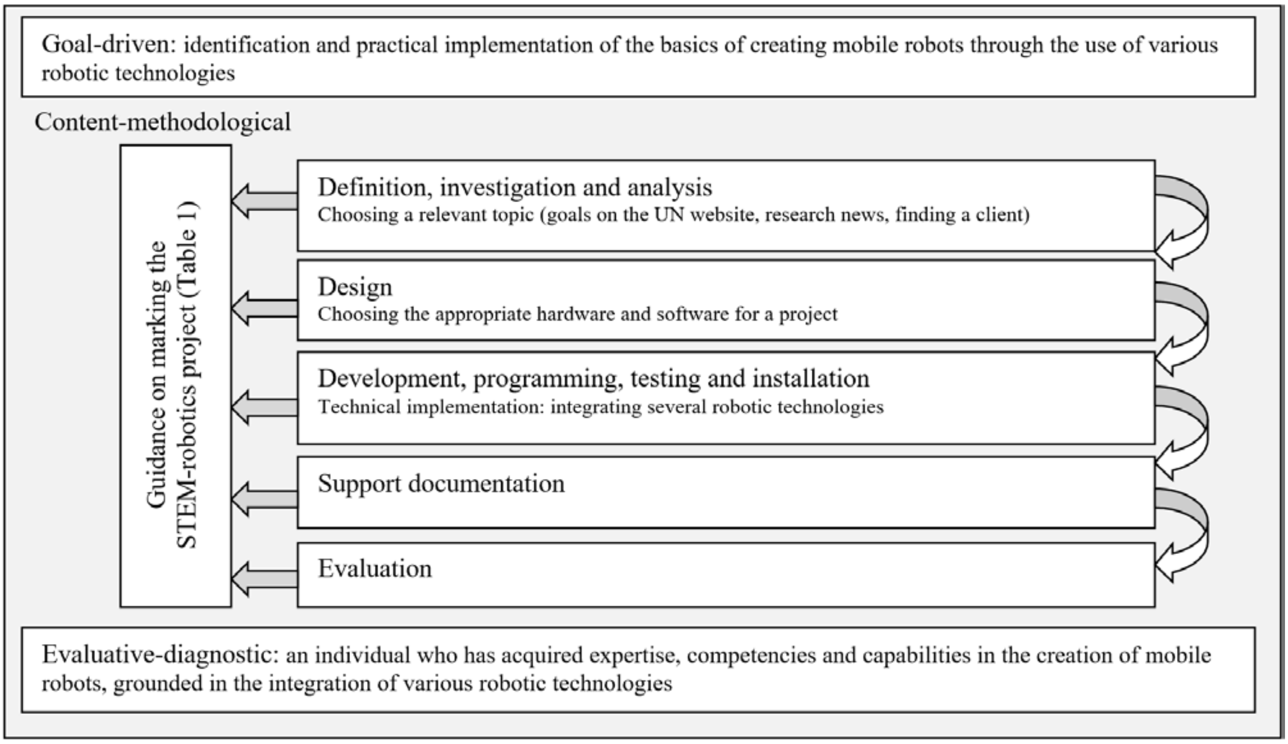



Figure 1: Model of training of future STEM specialists in the creation of mobile robots based on the integration of various robotic technologies.

The goal-driven constituent is committed to discerning and practically implementing rudimentary knowledge for fabricating mobile robots by harnessing many robotic technologies.

The content-methodological constituent revolves around the system life cycle methodologies for executing project tasks. The project represents a considerable endeavour requiring prolonged, systematic examination and formulation engagement.

In collaboration with their instructor, students select an articulated issue motivated by user needs. This issue should provide an opportunity to showcase their abilities in the systematic investigation, blueprint development and the creation of robotic solutions. This encompasses coding, validation, implementation, record-keeping and assessment.

The hardware integration involves robotic technologies, such as Arduino, Lego EV3 and computer vision. Three-dimensional printers and camp machines design the project's details and appearance. On the software front, using OpenCV-Python, cv zone, and media pipe libraries and creating efficient algorithms using C, Processing/Wiring is integral. STEM projects are evaluated against the criteria included in Table 1.

Table 1: Guidance on marking the STEM-robotics project.

| Technical/content criteria | | | | |
|---|---|---|---|---|
| | Developing (1-2 marks) | Good (3-5 marks) | Excellent (6-7 marks) | Superior (8-10 marks) |
| Definition, investigation and analysis | Description of the organisation and the methods currently used in the chosen project area. | Some evidence that an attempt has been made to interview the client and some recording of it has been made. An attempt has been made to develop a requirement specification based on the information collected. | Good client involvement and recording of the interview(s). Most of the necessary items have been covered, including a detailed discussion of alternative approaches. | Strong client engagement with comprehensive documentation of requirements. Detailed discussion of alternative approaches. Thorough system analysis for computerisation. Detailed specification based on collected information. |
| Design | Some preliminary discussion of what the system will do with a brief diagrammatic representation of the new system. | New system's primary objectives summarised with some omissions. Brief design specification includes mock-ups of inputs, outputs (I/O), and process model diagram. Incompleteness in process model (I/O). | Objectives clearly defined with complete design specification, albeit with possible errors or inconsistencies, such as inadequate validation or incorrect field lengths. Clear evidence of client feedback on the design and actions taken in response. | Agreed objectives and detailed, logically correct design specification. Detailed descriptions of processes/modules and clear data structure definition. Specification sufficient for development and testing with specified software and hardware. |
| Development, programming | Printouts of program listings or tailored robotics software provided. Developed solution does not meet design specification. | Printouts of program listings or tailored robotics software provided, including data structures with their purpose. Developed solution contains logical flaws and does not meet design specification. | Printouts of program listings or tailored robotics software provided, including detailed data structures. Complete set of input, output and data structure printouts. Developed solution meets design specification. Code annotations for logic understanding. | Printouts of program listings or tailored robotics software provided. Demonstrates good technical programming competence through self-documented listings with meaningful identifiers, indentation and control structures. Annotated code for quick logic understanding. |
| Testing, installation | Hardcopy test run outputs without a test plan or *vice versa* may exist. | Evidence of testing minimal with incomplete test plan and no relation between development and testing. | There should be hardcopy evidence from at least eight different test runs. | Detailed implementation plan including system changeover, training and user testing stages. Written client/user evidence of system testing. |
| Documentation | An incomplete guide, perhaps with no screen displays. Some options are briefly described but difficult for the user to follow. | All but one or two options are fully described (for example, backup routines not mentioned). | Complete, well-presented user guide with index and glossary. Some options, including backup routines and common error guide, described. | Comprehensive, well-organised user guide featuring index and glossary. Descriptions cover all options, including backup procedures and common error solutions. |

| | | | | |
|---|---|---|---|---|
| Evaluation | Discussion about work's success without referencing specification in design part. Effort made for user-friendliness, yet user still finds difficulty in system use. | Discussion on some objectives from the design part with omissions or insufficient explanations. System mostly user-friendly with room for improvement, e.g. lack of on-screen help. | Complete discussion addressing each objective from the design part, detailing the success degree, pointing to supporting evidence in the project or explaining reasons for unmet objectives. | A fully user-friendly system has been produced. The user indicates that the system fully meets the specification given in section design, and there are no known faults in the system. |

The evaluative-diagnostic constituent pertains to the development of an individual who has honed their expertise, competencies and abilities in designing mobile robots, predicated on integrating an array of robotic technologies. This individual is equipped to apply their knowledge in practical and applicable manners within the field.

The experimental work was supplemented with topics on various robotic technologies, including additional modules in the content of the courses Programming Micro Robots, and Autonomous and Social Robots of the programme 7M01525-STEM Education of *L.N. Gumilyov* Eurasian National University in Astana; and in the course content of the educational programme 6B06103-Computer Mechatronics, Fundamentals of Robotics-1, Mechatronics and Electronics, the educational programme 6B06101-Informatics, Programming of Robots at *Sarsen Amanzholov* East Kazakhstan University in Ust-Kamenogorsk. Questions on integrated robotic technologies were considered and covered by the teaching and methodological side.

Methodologies for Integrating Diverse Robotic Technologies

The study comprehensively explored the methodologies for unifying various robotic technologies, contributing to an intricate body of knowledge within this burgeoning field. Notably, the investigation scrutinised the following components:

1. Multi-EV3 integration: The study delved into strategies for synchronising multiple EV3 blocks into a cohesive system. It explored various connection modes, such as plume, engine-pressure sensor, Opto-para and engine-para. These techniques are fundamental in establishing communication between multiple robotic system components, enhancing its overall functionality.

2. Arduino-Lego intercommunication: The research focused on integrating Arduino and Lego systems, utilising the I2C communication protocol and opto-couplers. The I2C protocol enables data exchange between multiple systems, while opto-couplers provide insulation between different parts of an electric circuit, thus ensuring safe and efficient communication between Arduino and Lego.

3. Arduino-PC/Raspberry Pi connectivity: Furthermore, the study evaluated the usage of serial ports for establishing a link between Arduino and PC/Raspberry Pi systems, facilitating access to auxiliary databases. Serial communication is a foundational aspect of microcontroller programming and is critical for data transfer between various hardware components.

4. OpenCV, cv zone, media pipe integration with Arduino: Lastly, the study investigated the application of computer vision libraries - OpenCV, cv zone, media pipe - to interact with the Arduino microcontroller. These libraries provide tools for real-time image processing, object detection and tracking, thus enabling the creation of more sophisticated and interactive robotic systems.

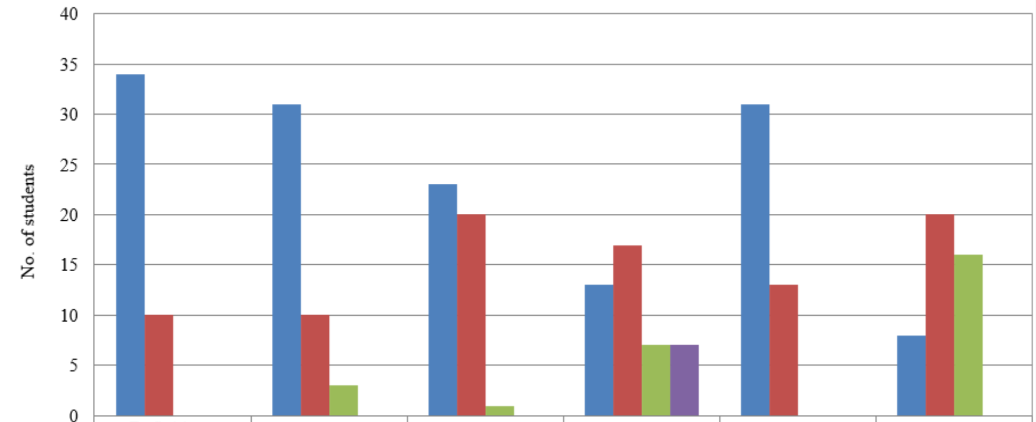
RESEARCH RESULTS

This study represents an extensive inquiry into the techniques for integrating multiple robotic technologies, thereby contributing significantly to the literature on robotic systems design and implementation. The student projects were analysed to evaluate the successful integration of the robotic technologies and the demonstrated learning outcomes.

The projects were assessed based on predetermined criteria for each stage of project work, such as the complexity of the tasks, the application of theoretical concepts and the demonstration of problem-solving skills [12].

This article offers some insights into the intricacies of student performance and pedagogical strategies in STEM-robotics education. Students were required to submit a progress report. The students' work included the following sections: definition, investigation and analysis; design; software development, programming; testing and installation; documentation; evaluation.

The outcome is measured in four technical dimensions that include developing, good, excellent and superior. Students performed the project work well, following the structure and sequence of sections by the assessment criteria (Figure 2).



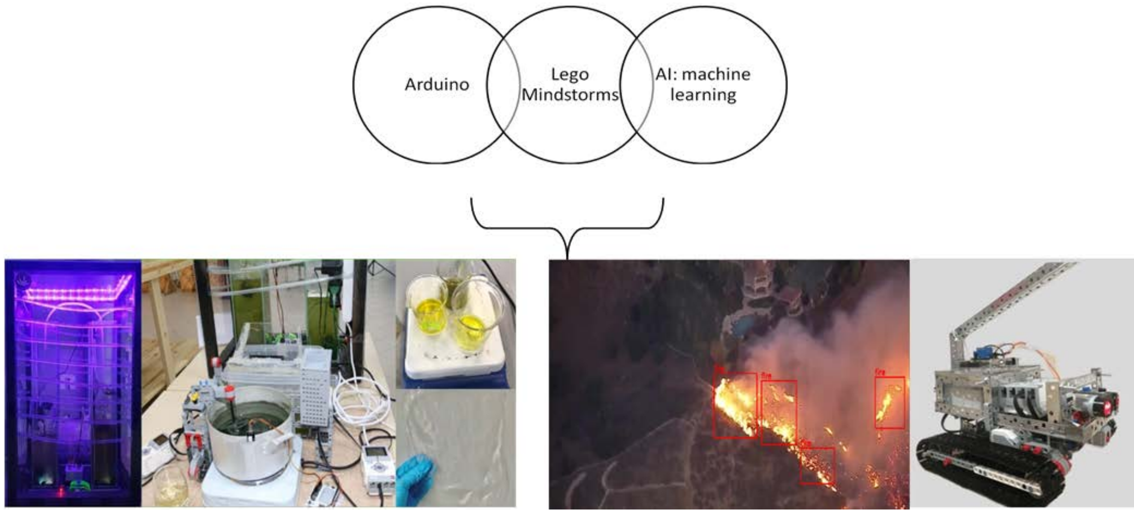

| | Definition, investigation and analysis | Design | Development, programming | Testing and installation | Documentation | Evaluation |
|---|---|---|---|---|---|---|
| Superior | 34 | 31 | 23 | 13 | 31 | 8 |
| Excellent | 10 | 10 | 20 | 17 | 13 | 20 |
| Good | 0 | 3 | 1 | 7 | 0 | 16 |
| Developing | 0 | 0 | 0 | 7 | 0 | 0 |

Figure 2: Continuous assessment of projects measured from the DIA, D, DP, TI, D and E stage.

The students exhibited a commendable proficiency in the research and analysis phase with a significant 93% demonstration of knowledge and applied skills. Similarly, a high competency level of 91% was observed in the documentation stage. In the design segment, the learners presented an excellent design of their respective projects, reflected in an 89% success rate. Nonetheless, during the project execution phase, certain functionalities did not align with the initial planning. Hence a marginally reduced effectiveness of 82% was noted. The evaluation stage manifested the lowest mean score of 80%. This was mainly due to students' partial achievement in self-assessment or client evolution tasks, indicating areas of potential improvement in self-evaluative abilities and client-focused assessment.

An Example of a Student's Research Project

Students from the STEM-education group at *L.N. Gumilyov* Eurasian National University developed and modelled projects that address two significant challenges of the contemporary time - climate change and forest fires - interconnected global environmental issues. The pertinence of these projects lies in their focus on technological innovation to mitigate these problems (Figure 4).




a) b)

Figure 4. STEM-robotics projects; a) photo-bioreactor; and b) forest firefighter robot.

Figure 4 presents a sample of student-developed projects, each exemplifying the innovative amalgamation of disparate robotic technologies. The first project explores a novel approach to carbon sequestration by integrating AI with biotechnology in creating an alga photo-bioreactor. The use of AI for optimising the processing and production of biomass presents a promising and innovative method for carbon capture, with algae shown to be significantly more efficient than trees in sequestering carbon dioxide [13]. As the effects of climate change continue to intensify, applying such technology could prove to be a game-changing strategy in the efforts to reduce greenhouse gases in the atmosphere.

The second project integrates neural networks, a form of artificial intelligence, to identify and combat forest fires. The burgeoning field of neural network applications in environmental monitoring and disaster mitigation has significant potential for enhancing the capacity to respond rapidly and effectively to such crises [14]. This project's integration of a neural network-based detection system into the design of a firefighting robot represents a significant advancement in the field, with considerable implications for forest fire management strategies.

## CONCLUSIONS

This research underscores the transformative potential of integrating diverse robotic technologies in executing high-calibre scientific projects. Each technology brings unique capabilities that, when harmonised, result in more sophisticated and versatile systems capable of handling complex tasks and producing advanced results.

Lectures and practical sessions reflected the use of diverse robotic technologies in the pedagogical approaches. Through methodologies, such as multi-EV3 integration, Arduino-Lego intercommunication, Arduino-PC/Raspberry Pi connectivity and the application of computer vision libraries, robust communication and control channels are established within the robotic system. These methodologies not only enhance individual component functionality but, more crucially, they unlock new dimensions of collective performance. Notably, the incorporation of computer vision libraries, such as OpenCV, cv zone and media pipe with Arduino demonstrates how the intersection of image processing and robotics can yield highly interactive and adaptive systems, opening new vistas for exploration in the realm of scientific research.

In a rapidly evolving technological landscape, the power of such integrated systems to accelerate innovation and discovery in various scientific domains cannot be overstated. Future research should continue to explore and refine these integration methodologies and harness their potential to drive the next generation of scientific breakthroughs.

## REFERENCES


1. Shulga, T.I., Zaripova, Z.F., Sakhieva, R.G., Devyatkin, G.S., Chauzova, V.A. and Zhdanov, S.P., Learners' career choices in STEM education: a review of empirical studies. *Eurasia J. of Mathematics, Science and Technol. Educ.*, 19, **5** (2023).
2. Serik, M., Yerlanova, G., Karelkhan, N. and Temirbekov, N., The use of the high-performance computing in the learning process. *Inter. J. of Emerging Technologies in Learning*, 16, **17**, 240-254 (2021).
3. Serik, M., Akhmetova, B., Shyndaliyev, N. and Mukhambetova, M., Supervising and managing STEM projects for school students by the school-university model. *World Trans. on Engng. and Technol. Educ*., 20, **2**, 95-100 (2022).
4. Eguchi, A., Robotics as a learning tool for educational transformation. *Proc. 4th Inter. Workshop on Teaching Robotics, Teaching with Robotics and 5th Inter. Conf. on Robotics in Educ*., 18, 27-34 (2014).
5. Lindh, J. and Holgersson, T., Does LEGO training stimulate pupils' ability to solve logical problems*? Computers & Educ.*, 49, **4**, 1097-1111 (2007).
6. Alimisis, D., Educational robotics: open questions and new challenges. *Themes in Science and Technol. Educ.*, 6, **1**, 63-71 (2013).
7. Williams, D.C., Ma, Y., Prejean, L., Ford, M.J. and Lai, G., Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *J of Research on Technol. in Educ*., 45, **2**, 131-152 (2012).
8. Chen, Y. and Chang, C.-C., The impact of an integrated robotics stem course with a sailboat topic on high school students' perceptions of integrative STEM, interest, and career orientation. *Eurasia J. of Mathematics, Science and Technol. Educ.*, 14, **12** (2018).
9. Benitti, F.B.V., Exploring the educational potential of robotics in schools: a systematic review. *Computers & Educ.*, 58, **3**, 978-988 (2012).
10. Ucgul, M. and Cagiltay, K., Design and implementation of a technology enhanced hybrid course on engineering in pre-college education: a LEGO Mindstorms NXT-based robotics curriculum. *Computers & Educ.*, 86, 23-36 (2015).
11. Dos Santos Matos, L., Rolim Ensslin, S. and Ensslin, L., A review on the performance measurement systems life cycle. *Lex Localis - J. of Local Self-Govern.*, 17, **4**, 939-959 (2019).
12. Rubin, H.J. and Rubin, I.S., *Data Analysis in the Responsive Interviewing Model*. In: Qualitative Interviewing: the Art of Hearing Data. Sage Publications, 12 (2012).
13. Becker, E.W., *Microalgae for Human and Animal Nutrition*. In: Richmond, A. and Qiang Hu (Eds), Handbook of Microalgal Culture: Applied Phycology and Biotechnology. (2nd Edn), Wiley-Blackwell, 461-503 (2013).
14. Ma, L., Liu, Y., Zhang, X., Ye, Y., Yin G. and Johnson, B.A., Deep learning in remote sensing applications: a meta-analysis and review. *ISPRS J. of Photogrammetry and Remote Sensing*, 152, 166-177 (2019).