Chapter 2
Teaching and Learning Robotics: A Pedagogical Perspective

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2.1 Learning Objectives

By the end of this chapter, you will be able to:

- Understand the current challenges in robotics course design in higher education
- Analyse current teaching practices and innovations in robotics teaching
- Reflect on the link between learning theories and pedagogies for designing robotics education
- Select and assemble suitable pedagogies and techniques for self-directed learning and development in the field of robotics.

2.2 Introduction

The previous chapter outlined technological developments and growth in the robotics field. The advancements and proliferation of robotics applications have had an enormous impact on our daily lives and have changed the skills and competencies of the emerging workforce (Ahmed & La, 2019). Ahmed and La (2019) argue for robotics integration into all levels of education to prepare the future workforce for a technologically advanced society. Considering the growth of robotics applications and the increase in robotics courses in academia, it is vital that the curricula of higher education be carefully designed to address graduate workplace demands. In that domain, there is an absence of systematic discussion and examination of robotics education,

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both of the syllabus and the pedagogies for addressing graduate student needs at tertiary level. This systematic discussion of teaching and learning practices is an imperative dictated not only from an education renewal perspective but also from the design and product development perspective in the newly developed industries that will have lasting and far-reaching societal implications.

This chapter aims to review current evidence-based research studies on robotics in higher education. Due to the expansion of robotics application in numerous fields, such as mechanical engineering, mechatronics, information technology, artificial intelligence to name a few, we reviewed research investigating teaching and assessment practices in robotics courses primarily in the last 10 years. This time frame will capture the current developments and innovations in the field and will provide a comprehensive understanding of effective teaching practices. These teaching practices will then be explained in the context of well-established educational theories and philosophies in adult learning with the goal of assisting teachers and academics in the design and selection of pedagogies and learning principles to suit robotics education.

In writing this chapter, we have two primary audiences in mind. First, we hope this discussion is applicable to teachers, academics and course designers of higher education robotics courses as it will introduce a bank of resources which they can use to design effective, pedagogically appropriate and industry-relevant curricula. Guided by learner-centred educational philosophies, and with an understanding of the link between educational theories and practices, it will contribute to a principled approach to the design, reflection and improvement in current educational practices, pedagogies and assessment in robotics education.

Second, the pedagogical discussion will be immensely valuable to students who are enrolled in robotics courses or who might want to advance their knowledge and skills in the field. It will provide them with a comprehensive understanding of the theories and pedagogies underpinning course design and a clear insight into interdisciplinary nature of the field. Knowledge and awareness of effective practices will empower and propel students to pursue their own learning and endow them with an array of strategies to learn autonomously and enhance their self-directed learning. Constructivist, constructionist and connectivist education theories (Bower, 2017) discussed in Sect. 6 in more detail, regard teachers as facilitators and guides of student learning and learning is seen as a continuous co-construction between learners and teachers. We hope that this chapter will provide them with an incentive and inspiration to continue their engagement in robotics, develop lifelong learning skills and exploit opportunities outside the university walls.

2.3 Defining the Body of Knowledge of the Robotics Field

An important starting point for designing an appropriate and relevant curriculum for any course is clearly delineation of articulating the body (mass) of knowledge, along with the skills and learning outcomes of any course. This process is guided by curriculum design principles, which view curriculum design as dynamic, comprising a series of interconnected stages: theoretical and epistemological beliefs about the nature of learning, needs analysis, definition of aims and learning outcomes, syllabus design and assessment, methodologies and pedagogies for implementation and the evaluation plan (Richards, 2017). This process suggests that each of these stages is not acting independently, but is mutually dependent on one another. In order to address the research gap in the educational robotics literature and guide the development of robotics courses in higher education, this chapter will survey the literature to identify the body of knowledge expected of graduates of robotics and review the current pedagogies and practices in the robotics field, with a view to suggesting a more holistic approach to robotics education that transcends the traditional boundaries and domains.

Despite the wealth of research in the robotics field, there have been few attempts at describing the body of knowledge expected for those working in the field. To date, we trace the most recent discussion of the body of knowledge and skills for robotics to two reviews in 2007 and 2009 which we summarise here in an effort to describe the state of the art in the field and further illustrate the challenges facing academics today (Gennert & Tryggvason, 2009; McKee, 2007).

While robotics is a field that is taught in various courses and disciplines such as engineering, computer science, information technology, it is common knowledge among researchers that the field is highly diverse and draws on a variety of disciplines (Berry, 2017; McKee, 2007; Wang et al., 2020). According to McKee (2007), this knowledge goes beyond traditional fields of study such as mathematical modelling and machine learning but includes key theoretical and practical dimensions that reflect the diversity in the field: it can cover areas such as mathematics, computing, control engineering, electronic systems, computing systems, programming and algorithms, robotics systems and practice, artificial and computational intelligence, human–computer interaction, artificial intelligence, algorithmic and mathematical modelling, machine learning (McKee, 2007). The multidisciplinary nature of robotics poses several challenges for curriculum developers in the field and calls for a systematic and theory-driven approach to the design of tertiary curricula. In the second study, Gennert and Tryggvason (2009) highlight the importance of defining the body of knowledge necessary for robotics education and preparing ardent prospective robotics engineers to handle the complex nature of robotics applications. They argue that robotics education must not simply attempt to transfer knowledge but attempt to "educate innovators who will have the imagination to shape our world" (p. 20). Discussing their difficulties in their own course design, they identify certain gaps in robotics education:

- Robotics engineering does not seem to have a firm intellectual basis, which is necessary for defining the knowledge and skills required for undergraduate courses in robotics.
- Robotics engineering is not an accredited programme of study and the authors recommend that researchers identify the body of knowledge expected.

- Robotics engineering should bridge the gaps between the scientific, theoretical knowledge and hands-on industrial knowledge.
- There is insufficient research on appropriate curricula and syllabi for robotics engineering education.

Besides the interdisciplinary nature and skills needed in the design of robotics courses, other compounding factors include the role of robotics courses in different disciplines, schools and faculties, and the selection of content to meet the level of prerequisite knowledge expected of students when enrolling in a robotics course (Berry, 2017; McKee, 2007). These concerns are further compounded by the challenges of balancing theory and practice (Jung, 2013), the appropriateness of selection of teaching methods in robotics courses and the design of assessment that evaluates students' achievement of skills in practical and theoretical understanding (Jung, 2013).

A comprehensive inspection of the educational literature on robotics reveals that the current teaching of robotics has not changed dramatically, since the studies in 2007 and 2009, despite the wide applications and developments in the research space (Berry, 2017; Jung, 2013). This is the point of departure for the present chapter which will review a series of studies that pioneer innovative pedagogies and assessment in robotics and which will guide our subsequent theoretical discussion and recommendations for pedagogical approaches in the robotics field.

2.4 Review of Research on Pedagogies and Practices in Robotics Education

Due to the STEM integration in school years, robotics engineering has widespread appeal among university students (Berengual et al., 2016; Gennert & Tryggvason, 2009; Hamann et al., 2018; McKee, 2007; Wang et al., 2020) and this appeal has captured the attention of educators. Educational practitioners and researchers in the field highlight the need to shift away from traditional modes of delivering robotics education (McKee, 2007) to encapsulate the diverse applications of automata, integrate interdisciplinary research and resolve some of the aforementioned tensions. Given the technological advancements, innovations have been introduced in the delivery of courses which include virtual learning environments, virtual robotic laboratories and mobile robotics education to support distance and online courses in robotics (Gabriele et al., 2012; Khamis et al., 2006).

This section reviews current research on educational robotics and reports on innovative pedagogies and content selection employed in the design and teaching of robotics courses, especially in the last 10 years. The research studies originate in courses which received favourable student evaluations and led to improved learning outcomes (Gabriele et al., 2012; Jung, 2013; Wang et al., 2020). The presentation will pave the way for revolutionising higher education robotics courses and assist students and teachers in identifying pedagogical tools for autonomous learning development and teacher curriculum development.

2.4.1 Adaptation of Content from Different Disciplines

One of the key challenges is the selection of suitable content for robotics courses that target the needs and knowledge of different disciplines and subfields. For instance, Gennert and Tryggvason (2009) discuss the design of their robotics undergraduate course in a Polytechnic university aiming to teach the basic fundamentals to students in mechanical engineering, computer science and electrical engineering. In addressing the different student background knowledge, the syllabus integrated a unique range of modules on areas such as power, sensing, manipulation, and navigation, adjusting and incorporating content from each of the students' disciplines. In another study discussing the review of a robotics course in the faculty of mechatronics at a Korean university, Jung (2013) raised the need to combine theory and practice by integrating knowledge in Manipulator robots with hands-on experiences in laboratory practicals. The course incorporated interdisciplinary theoretical content covering robot kinematics, dynamics, path planning and control, while the laboratory practical experience made use of a range of robot applications, experimental kits, Lego robots and humanoid robots to develop student skills in motor control. Wang et al. (2020) and Hamann et al. (2018) share these views and stress that, because of the popularity of robotics as a discipline and its cross-disciplinary nature, new methodologies and content need to be developed to allow students to combine hardware and software implementation and to prepare future engineers to handle unfamiliar and complex problems. This complies with current educational curriculum principles, which recommend a thorough analysis of the context and student needs in the courses to design relevant and student-centred courses.

The development and redesign of new robotics courses and the increasing diversity of contexts of robotics have led to the emergence and necessity of new pedagogies to engage students in the field and to design appropriate content effectively (Martínez-Tenor et al., 2019). Similarly, Wang et al. (2020) argue that new methodologies need to be developed to allow students to combine hardware and software implementations.

2.4.2 Constructivist Approaches to Learning

An important consideration emerging in this research is the importance of educational theory in underpinning curriculum design and assessment. Few studies identified the role of combining instructivist or didactic and constructivist paradigms in course design (Johnson, 2009; Martínez-Tenor et al., 2019). Instructivist pedagogies are associated with traditional forms of learning such as lectures, videos and examinations where learners aim to gain knowledge. Constructivist modes of instruction focus on student engagement in active participation and problem solving, where teachers are facilitators and enablers of student learning. The constructivist paradigm is typically associated with activities and pedagogies such as task-based learning, collaborative activities, group tasks in which students engage in problem solving and learning through collaboration and exchange. A revision of a recent master's course (Martínez-Tenor et al., 2019) on cognitive robotics led to the integration of two approaches using Lego Mindstorm. Students were first exposed to instructional videos on machine learning and reinforcement learning as a preparation for their engagement in interactive sessions using reinforcement learning working on two decision-making problems. Students' evaluation of the teaching methods in the course showed that students appreciated and benefitted from autonomous learning and collaborative learning activities and found the possibility of programming a robot intensely motivating. They also offered suggestions for improvement, which could be considered in future courses. These comprise time allocation for analysis and reflection on the experiments, addition of problem-solving activities, increasing opportunities for collaboration, reflection and retention by students. Martinez-Tenor et al. (2019) echo Johnson's suggestion (2009) for a carefully designed programme that combines instructivist and constructivist approaches to teaching to address diversity in learning styles.

2.4.3 Situated Learning Methodology

Wang et al. (2020) discuss the implementation of an innovative pedagogy, which they name situated learning methodology combined with the development of a hands-on, project-oriented robotics curriculum in an undergraduate and postgraduate unit for computing students. To address the challenge of combining theory and practice, the course employed a situated learning-based robotics education pedagogy, guided by four central principles: content, context, community and participation (Stein, 1998). The situated learning methodology assumes that learning is a process of participation and practice for solving real-life authentic problems (Lave & Wagner, 1991). Based on the belief that knowledge and skills are developed effectively in the context of real life, situated learning allowed students to work on a real-life application: interacting with a multimodal collaborative robot who is employed as the students' classmate. A classroom-based learning community is established with groups working on solutions to different hands-on tasks. The situated learning approach could be regarded as a technique belonging to the constructivist education paradigm that promotes collaboration and co-construction of learning in authentic real life environments (Selby et al., 2021).

2.4.4 Flipped Classroom

Another novel method introduced in a mobile robotics course in a US university was the flipped classroom (Berry, 2017). This method was adopted to address time limitations in explaining the theoretical components of robotics and encourage more student participation (Berry, 2017). The flipped classroom is a new pedagogical method which distinctively combines instructivist and constructivist approaches to learning. The term “flipped classroom”, often referred to as “reversed instruction”, incorporates a switch between in-class and out-of-class time, thus fostering more interaction between teachers and students during class time. Students spend most of the time engaged in experiential activities, problem solving and diversified platforms (Nouri, 2016). A meta-analysis of flipped classroom research has demonstrated the effectiveness of this model over traditional learning on student achievement and learning motivation (Bergmann & Sams, 2012). The flipped approach was utilised in the course to allow students to focus on their development of technical skills in controlling robots, designing and experimentation with the real mobile robots for laboratory experiments. This model has enormous potential for addressing the challenges of balancing theory and practice in a university course and allowing adequate time for problem solving, self-paced learning activities and student negotiation.

2.4.5 Gamification

Another area of increasing interest is the role of gamification in robotics education, which refers to the addition of play-based elements such as games as a method of instruction to increase student engagement. Hamann et al. (2018) discuss the gamification in teaching swarm robotics to first-year undergraduate students in computer science, with a focus on teaching/learning theory and practice. Videogames allowed student immersion in a simulated environment and inspired student creativity. Students were presented with several robot manipulator challenges, engaged in designing fully working prototype robots and models from the start with a gradual increase in their functionality and complexity. The curriculum integrated robot-based videogames and student competitions, thus building students’ teamwork skills and triggering their imagination and engagement. Simultaneously, these learner-centred methods offer students flexibility in learning and enhance their autonomy in problem solving and engineering.

2.4.6 Online Interactive Tools

The advances in educational technologies have impacted education worldwide by creating a variety of online tools and technological affordances. The educational domain experienced a boom in online learning and hybrid learning modes which led to the creation of several online and virtual tools. To facilitate online delivery of robotics courses, virtual laboratories were used engaging students in building and guiding robots remotely with a range of tools. For instance, Berengual et al. (2016) employed an array of interactive tools which they defined as "a set of graphics windows whose components are active, dynamic and clickable ones" in order to practice the theoretical aspects of the course. The "Mobile Robot Interactive Tool" (MRIT) aimed at teaching students about robot navigation, allowing students to explore a variety of parameters, such as robot kinematics, path planning algorithm, the shape of the obstacles. It assisted students in understanding the basis of mobile robot navigation and allowed them to modify different characteristics, such as robot kinematics, path planning algorithm and the shape of the obstacles. The second interactive software tool, the slip interactive tool (slip-IT) was used to teach the concept of slip in off-road mobile robots and last for the teaching of robotics manipulation MATLAB/SIMULINK and robotics toolbox for conducting robot simulations. The courses integrated two robots, some of which could be controlled remotely or offline through Internet connection to the labs allowing students to work remotely. In addition to the simulation activities, the adoption of a real robot for demonstration and implementation was a fundamental aspect of the course. Another interactive tool, called ROBOT DRAW, was discussed by Robinette and Manseur (2001), which has been widely used in robotics education. The tool was designed to enable students to easily visualise robots in various configurations and evaluate the effect of a parameter variation on the robot. Among others, a popular online platform (https://www.theconstructsim.com/) provides a range of online robot manipulation tools and can be used by both students and teachers for autonomous practical learning. It consists of virtual laboratories allowing students to experiment with manipulating, building real and virtual robots online using a range of tools. Exposure and interaction with a range of tools build students' technological competencies and problem-solving skills.

2.5 Assessment Practices

Changes in pedagogies and methods in teaching are closely intertwined with transformative assessment practices that match the learning–teaching philosophies of these methods. Traditional methods of assessment have been embedded in many higher education courses and comprised examination-based assessment or/and experimental work. A few attempts have been made to modify assessment practices to reflect changes in pedagogical approaches in robotics.

2.5.1 Collaborative and Individual Project-Based Assessment

The majority of new assessment tasks integrated into some courses comprise project-based assessment and competition reward systems. Group and individual projects provide opportunities for authentic and collaborative learning experiences and enhance student motivation and problem solving. In the design of courses reviewed by Hamann et al. (2018) and Jung (2013), student assessment consisted of a group project using competition-based learning, in which students had to engage and collaborate through a series of tasks in a boxing match, using humanoid robots. Students found the competition-based assessment a valuable and motivating experience in applying many theoretical robotics skills although they acknowledged the challenges of the time requirement of the competitions (Jung, 2013). Similarly, Wang et al. (2020) employed project-based assessment allowing students to create a complete robot control architecture in software and hardware during laboratory sessions. This form of assessment enabled a classroom-based learning community with groups working on solutions to different hands-on tasks. Consistent with the situated teaching methodology, project-based learning was adopted: each student was equipped with a robotics development kit containing ultrasonic sensors, an Arduino board and other robotics electronic accessories. The practical hands-on application, combined with the step-by-step progression part of the syllabus and the teaching methodology, led to student satisfaction and the effectiveness of this approach in the development of students' learning outcomes. Berengual et al. (2016) equally employed a project-based group assessment expecting students to build, programme and navigate a robot, and a series of online reflections on theory and laboratory participation in a range of tasks that assisted with the group project. Students identified the project task as one of the most vital educational experiences that developed their technical and engineering skills. Last, using a simple to complex curriculum design model, Hamann et al. (2018) report on the use of group project allowing students to progress the robot applications through a series of phases from simulation to real robots leading to a battle royale game. The adoption of games and competitions both as sources of learning and assessment offer students opportunities for collaboration, development of student autonomy in problem solving and engineering and allow students to see and test the effects of their programming and engineering.

2.5.2 Competition-Based Assessment

As mentioned previously, competition-based assessment can be a powerful tool in engaging students in collaborative assessment. It was integrated into Martínez-Tenor et al. (2019) and Jung (2013) course design studies and contributed to rich learning and increase in student engagement and motivation. Some courses used project-based learning to generate conference presentations which offered multiple opportunities for student academic development, rich learning and networking with industry.

2.5.3 *Reflective Learning*

To foster deep processing of learning, reflective writing in the form of continuous assessment such as reflective posts was also introduced in some robotics courses. The use of reflective activities is often combined with other forms of assessment such as group projects which integrate experimental work with reflective writing where students explain and focus on consolidation of theoretical knowledge. Wang et al. (2020) designed project-based assessment expecting students to work towards creating a complete robot control architecture in software and hardware during laboratory sessions. Assessment was redesigned to include weekly literature reflections, online quizzes on the theory and staged group project assessment conducted in laboratories consisting of three graded components: a demonstration, a technical memo and a code submission. Martínez-Tenor et al. (2019) also incorporated reflections as part of the group/project assessment focusing on robot manipulation, which resulted in a valuable learning experience for students. Individual reflections also allow for flexibility and self-paced learning and when shared publicly in online learning platforms offer rich learning opportunities for all students in the course.

The aforementioned discussion identified some attempts at transforming teaching/learning practices and assessment in robotics higher education courses based on a review of educational research in the last decade. To truly transform education practices and to identify effective teaching pedagogies in robotics education and beyond, it is vital for teachers and students to develop an advanced awareness of the relationship between education theories, curriculum design principles and methods of learning and teaching. Equipped with these skills, academics, teachers and students can make systematic and theory-driven selections to revise, adapt and refine robotics education.

2.6 Paving the Way for Innovative Pedagogies and Assessment in Robotics Education

To address the call for more diverse and current educational practices, to tackle the current diverse applications of robotics and the growth of the industry, it is important that robotics education prepares future engineers adequately to cope with arising challenge in the field (Wang et al., 2020). This section will provide a guide to novel pedagogical practices and assessment in teaching robotics, relying on research in educational literature and the challenges facing robotics education at the academic level. Important caveats for applying these suggestions will be discussed at the end of this section.

First, we will begin with a discussion of educational theories/epistemologies that drive pedagogical practices, as this is an integral aspect of any teaching and curriculum design process (Richards, 2017). Research on adult learning and education theory is well-established, highly researched and has undergone many transformations. Educational theories and ideologies are defined as a set of epistemological beliefs concerning the nature and value of learning, teaching and the role of education and serve as a justification for particular approaches, pedagogies and methods to teaching (Richards, 2017).

Historically, one of the first theories which influenced educational processes was behaviourism which viewed learning as habitual behaviour, that is, observable, conditioned upon a stimulus-reward action and reinforced through habitual learning (Skinner, 1974). Influenced by a series of experiments on dogs, Skinner (1974) concluded that learning is observable through actions and is shaped by the environment and instructional design. He continued to suggest that learning can be achieved through a series of teacher questions and student responses, where positive and negative feedbacks determined the learning process. The behaviourist learning theory influenced educational design, by emphasising that teaching is an objective body of knowledge that is to be delivered and measured though performance measures and outcomes (Bower, 2017; Howell, 2012). The behaviourist approach is associated with the transmission-based model of teaching placing teachers as the authority of knowledge, organisers and planners of learning and learners as passive recipients of this knowledge. This is evident in traditional and authoritative models of teaching and classical forms of assessment such as examinations, quizzes, not acknowledging the role of the learners in the process or other environmental or psychological factors (Bower, 2017). Despite the early successes of the behaviourist paradigms, one of its drawbacks was the lack of consideration of the complexity of human cognition and the individual learner processes.

In addressing the limitations with the behaviourist theory, another group of researchers examined the role of mental and information processing in the learning process, which LD to the development of cognitivism. Within the theory of cognitivism, learning is an internal mental process of storing, receiving, consolidating and reorganising information and knowledge structures or schemata (Bower, 2017). Cognitivism could be seen as an extension of behaviourism, with attention to the workings of the brain. Proponents and researchers in the field focused on aspects of selection, organisation and retrieval of information and used some of this research to design a curriculum with learner conditions in mind. These included aspects of knowledge sequencing, information load, staged instruction to improve learning comprehension and consolidation. However, within cognitivism the transmission model of education and the focus on demonstration of learning outcomes prevailed.

This gave way to the theory of constructivism, one of the most influential paradigms that focused on learning as a process rather than learning as a product. Constructivist paradigms have dominated modern educational practices at all education levels (Jones & Brader-Araje, 2002). The paradigm is based on the idea that learning is not static but dynamic and is a process of reflection, negotiation and individual or collaborative discussion through interaction with other learners, interaction with social and cultural influences. Individual constructivism was pioneered by Piaget (1970), who considered learning as a result of processes of assimilation and accommodation of new knowledge to existing knowledge, while social constructivism, introduced by Vygotsky (1978) focused on sociocultural influences on learners and their learning. Within Vygotsky's social constructivism (1978), group activities and collaborative learning are preconditions and must precede any individual learning. Learning is regarded as a continuous interplay between others and the self through internal assimilation and extension/addition of new knowledge. Intrinsic to the social constructivist model, which has had tremendous impact on learning, is the idea of scaffolding, which is defined as additional assistance and support which can gradually be removed after the learner has gained independence. Based on the constructivist perspective, the teachers are considered guides and facilitators and providers of the conditions, tools and prompts enabling students to discover principles and engage in knowledge construction by themselves (Bruner, 1990). The constructivist paradigm gave birth to several teaching methodologies that promote co-construction, negotiation of learning and self-discovery, comprising students' engagement in self-directed learning but also and most importantly collaborative learning, project-based learning and competitions-games and tournament tasks (Jones & Brader-Araje, 2002).

Constructionism is regarded as an extension of constructivism which considered the impact of technologies and artefacts on the learning process. The origins of this theory can be traced to Papert (1980) who observed that learners create their own reflections through experimentation with tangible objects, which were initially referred to Lego, Logo and Mindstorms. It was suggested that learning takes place when people are active during their creation of tangible objects in the real world. It further assumes that learning is reinforced through engagement in authentic tasks, creation of tangible objects, collaborative learning or other design activities in the real world such as authentic and situated learning experiences (Howell, 2012; Papert & Harel, 1991).

With similar roots to constructionism and inspired by the digital networking, researchers introduced connectivism as the new epistemology based on the dominance of digital learning. Connectivism subscribes to the views that learning takes place in an organic fashion and is a result of building connections and skills in connecting the digital world, technologies and platforms with social networks, knowledge and information (Siemens, 2005). It centres on the metaphor of networks with nodes and connections as the basis for learning. Influenced by constructivist principles, connectivism is a novel approach, adopted in technology-enhanced learning and online learning, and aims to develop students' skills in critical thinking, connecting and collaborating through interactions with technologies and connectivist learning environments (Bower, 2017; Howell, 2012; Siemens, 2005).

It is evident in the above review that there has been exponential growth in educational theory, which in turn generated new methods and pedagogies that could be integrated into robotics education. Some of these new methods employed in the course design literature identified in Sect. 4 were influenced by constructivist, constructionist and connectivist ideologies and were considered effective. Given the role of robotics education in preparing the undergraduate students in handling complex real-life problems, curriculum design in the field could benefit from integrating such novel methodologies.

While traditional didactic learning is an integral aspect of acquiring key knowledge, admittedly, to align with current research developments in learning theories and to address today's global challenges and to develop competitive and multi-skilled graduates, it is vital that robotics education be enriched to bring about more educational benefits. Instructivist, behaviourist and cognitivist methods have dominated the delivery and implementation of higher education courses but they are limited and inadequate in improving learning outcomes. This section will highlight novel and evidence-based pedagogies that could improve robotics course design and facilitate graduates' self-directed learning.

Some of the most effective pedagogies that are consistent with constructivist and constructionism theories are collaborative learning, project-based learning and competition-framed tasks. These methods should play a significant role in the delivery of robotics education in academic as well as other educational levels. There is abundant research to suggest that social engagement and collaboration with peers have positive impact on individual development, problem solving as well as social collaboration skills, skills and attributes expected of university graduates (Zheng et al., 2020). Collaborative learning can be enhanced through discussion forums, web-conferencing systems, virtual worlds, project-based learning during experimental work. Collaborative learning allows students to treat their collaborators as resources and guides for their own growth and development. It also provides opportunities for scaffolding by allowing for information exchange and learning from one another and teamwork skills on problem-solving activities. It needs to be mentioned that project-based learning comprising group collaboration comes with several challenges. These challenges can be frustrating for students, but with sufficient guidance, they can empower students, help them develop student independence, creativity and equip them with innovative problem-solving skills.

Project-based learning can sometimes take the form of problem-based learning and design-based learning, which all align with constructivist and constructionist principles. Design-based learning is a novel learning approach encouraging students to work collaboratively on authentic real-life design tasks with the aim of advancing their design skills, problem-solving abilities, reasoning and critical thinking skills and develop attitudes to continuously tackle emerging challenges (Howell, 2012; Kim et al., 2015). Problem-based learning is a pedagogical technique that provides students with an authentic problem, with the aim of advancing student engagement and motivation and supporting student-centeredness, self-regulation, development of cognitive and metacognitive strategies, autonomy and student independence (Stefanou et al., 2013). It has also been suggested that project-based learning is easily combined with other methods such as flipped classroom models, inquiry-based learning, collaborative learning, and the combination of such methods maximises the effectiveness on student learning (Zheng et al., 2020).

Last but not least, competitions, games, tournaments combined with or incorporated in collaborative projects enhance students' motivation and interest to learn and encourage independence and further learning. Games are built on constructivist principles and promote cognitive and social interaction, and build risk-taking, strategic negotiation, problem solving, collaboration, reflection and lateral thinking (Gee, 2005). They can increase student engagement, motivation and promote a high sense of achievement and competition (Stefanou et al., 2013). Gamification principles could be used as learning approaches or as assessment tools and have the potential to increase students' continuous engagement and excitement in the course and the range of activities (Hwang & Chang, 2016).

Changes in learning methods and pedagogies implicate changes in assessment practices. An effective curriculum expects consistency between the syllabus, pedagogies and assessment practices, a notion known as "constructive alignment" (Biggs, 2014, p. 5). The aforementioned literature has paved the way for integrating a wide range of assessment items that align with constructivist and project-based approaches to learning.

Educational research points to the significance of project-based assessment, as it offers authentic learning experiences for students, builds their collaborative skills and develops their problem-solving skills. It is consistent with the new pedagogies promoted in the previous review and would also endow students with skills for the real world where teams work together to build, design and manipulate robots.

Due to the multidisciplinary aspects of robotics and its contribution to a range of fields, robotics courses could benefit from online reflections on the literature and theory. This was assumed and encouraged in the early work by Papert (1980) who suggested that knowledge is created through reflection and engagement with people and artefacts. These online reflections could be used as formative assessments to engage students' reflective, critical learning skills and problem solving abilities (Merlo-Espino et al., 2018). Reflective activities and discussions can also be integrated into project-related work to assist students in resolving these challenges and offer a mechanism of getting support from lecturers (Serrano et al., 2018).

Admittedly, authentic assessment should be an indispensable component of robotics assessment in higher education. Authentic learning is a suitable pedagogy that operates within the theory of constructionism, hypothesising that learning takes place during students' interaction with practical tasks and robots. Authentic assessment, therefore, refers to assessment requiring students to build/design/create artefacts or robotics applications and provides them with opportunities to develop real-world skills. Gulikers et al. (2004) highlight a number of aspects of authenticity in assessment: the task, the physical, virtual and social context, the artefact produced (or behaviour assessed) or/and, the criteria and expected standard. Authentic assessment assists the students with developing competencies appropriate for the workforce and is often requirements for meeting professional accreditation standards. Project-based assessment that enables students to design a robot-based application is paramount to developing students' real-life skills and foster effective human–robot interaction (Gurung et al., 2021). They further enhance situated learning/learning by doing (Wang et al., 2020) as they provide the environment for students to learn from one another and develop collaborative skills.

An important caveat needs to be mentioned here. The choice of assessment tasks, formative, summative, group and/or individual need to be closely linked with the pedagogy and epistemology of the course, syllabus and the teaching, something known as epistemological alignment to improve the course success. There must be an effective triadic relationship between epistemology (the nature of learning), pedagogy an assessment for the course to be successful and meet its objectives (Knight et al., 2014).

It is important to highlight that these suggestions are pertinent to students who are studying in robotics and robotics adjacent fields. Students interested in advancing their knowledge and skills can seek opportunities, extra-curricular and industry opportunities to be involved in authentic projects, collaborative activities and pursue conference or industry presentations. Reflective learning activities and participation in discussions can create valuable learning opportunities for students to advance their skills and be competitive in the field (Fig. 2.1).

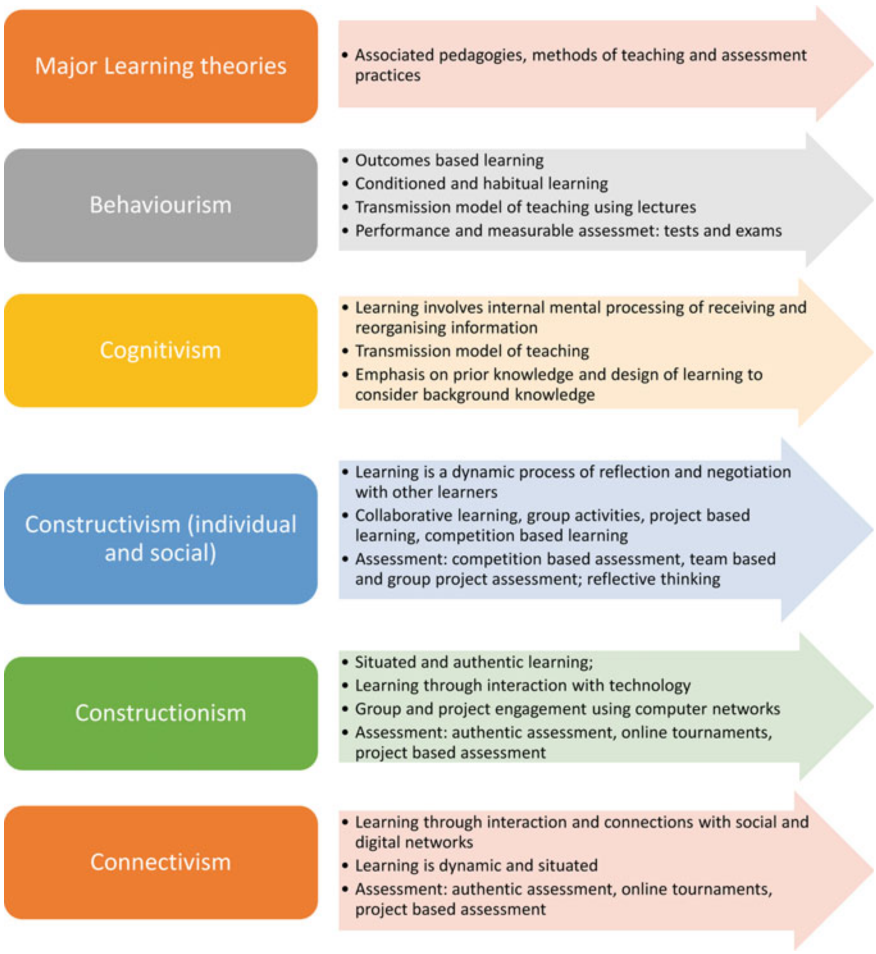

Fig. 2.1 Learning theories, principles and pedagogies

2.7 Chapter Summary

In addressing the absence of systematic reviews of research and recommendations in teaching robotics, this chapter offered an overview of the current challenges in teaching and learning robotics and reviewed pedagogical trends in robotics education at higher education institutions. The need for a systematic presentation of current educational practices is further enhanced when considering that the purpose of the book is to introduce the theory, design and applications of robotics for students and academics, and to advance students' skills to handle complex problems. This chapter first highlighted several challenges facing designers of robotics courses which include lack of systematic research in robotics education and the complex network of disciplines which need to be synthesised to design robotics courses. Next, it reviewed current innovations in higher education course design and pedagogy, specifically focusing on the last ten years, which were found to lead to improved learning outcomes. This aimed to raise students' awareness of the history and theoretical principles underlying the teaching of robotics at the academic level. To address the challenges and complexities in designing appropriate syllabus and instruction, and the need to shift away from traditional forms of learning, the last section offered a comprehensive understanding of learning theories and relevant pedagogies that have the potential to improve educational practices and lead to learning benefits if used appropriately in robotics education.

To shape the future of robotics education, it is imperative that academics, teachers and industry practitioners work collaboratively and be involved in negotiating and co-designing the syllabus and assessment of academic robotics courses. In addressing the chasm in the knowledge, we hope this chapter developed their in-depth awareness of the theoretical basis of teaching pedagogies and advances in learning theory which should guide course design, syllabus and assessment. Learner-centred, constructivist and connectivist learning theories should be the basis for selecting suitable methods which address the challenges embedded in the multidisciplinary nature of robotics, and the diverse skills engineers need in today's technologically advanced society. These pedagogies comprise project-based learning, problem-based and collaborative learning, reflective writing and authentic assessment, to name a few.

Revolutionising robotics education and building work-ready graduates are not simple tasks. Recognising the complexity of the robotics field and the diversity in educational processes is a starting point which can assist in our definition of roles, responsibilities and identities as learners and teachers. It requires changes in beliefs and practices that both students and teachers implement and manage effectively. Zhou et al. (2020) argue that students' dissatisfaction in academic courses is often ascribed to their lack of understanding of their role in the learning process and, of the epistemological beliefs underpinning learning and assessment (Zhou et al., 2020). Teachers should be willing to adopt such roles as guides, facilitators, moderators of learning and enablers of change, and invite students in negotiations and co-constructions of their learning experiences. Armed with tools and strategies to improve their learning, students should be co-creators and active participants of classroom realities (Harmer, 2015). Students need to engage in sociocultural and professional practices in robotics, shaping and negotiating their identities and social relations in this academic community of practice (Saltmarsh & Saltmarsh, 2008). It is hoped that with the discussion in this chapter, students are empowered and inspired in taking charge of their own learning and armed with a multitude of tools to continue their professional development and lifelong learning.

2.8 Quiz

According to this chapter,

- What are some key challenges facing robotics education course design?
- What were some of the pedagogical innovations discussed and reviewed in the robotics literature in this chapter?
- Name some interactive tools which have been incorporated in teaching robotics in higher education.
- What is the learning theory which espoused the idea that knowledge is built when we interact, experiment and reflect on our experience by building and creating artefacts?
- What are some methods that you can employ to advance your skills in robotics?

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