Selecting an Educational Robot: a Comprehensive Guideline

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Abstract. The emergence of educational robots has revolutionized the manner in which students access education, leading to a surge in the popularity of educational robots. The process of selecting the right robot hardware for educational purposes holds great importance, as it can significantly impact the learning experience and subsequent outcomes. Due to the continuously growing market of educational robots, several critical factors must be carefully considered to effectively choose the most suitable robotic kit for a specific educational activity. Our study has two primary objectives: Firstly, it aims to identify crucial criteria for selecting an educational robot by conducting a thorough review of existing literature. Secondly, our goal is to offer a comprehensive guideline that meticulously outlines seven steps for choosing the most suitable robot. In addition, we provide guidance on the practical application of our policy through the use of a case study.

Keywords: educational robots · selection criteria · guidelines

1 Introduction

The positive effect of mobile robots in education is undeniable [7,13]. Thus, given the continuous advancement of technology, the integration of mobile robots in education appears increasingly imperative [5,19]. This is emphasized by the large number of mobile robots developed specifically for education, although the diversity available in the market complicates the process of choosing an appropriate robot [4]. Therefore, finding a robot suitable for a specific use in education requires some effort. To aid in the selection process, the paper examines two key research questions (RQ):

- **RQ1:** What criteria should be taken into account when selecting mobile robots for educational purposes?
- **RQ2:** How can a mobile robot be selected based on the criteria?

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Accordingly, general criteria for the selection of mobile robots are identified. This is accomplished by building upon existing research. Furthermore, we present a case study to illustrate the practical application of these criteria. Our case study focuses on choosing a mobile robot for a higher education setting. Specifically, we aim to systematically create a new course on mobile systems as part of a newly established Bachelor's degree program. This objective is part of a funded project to develop the Bachelor Programme *AI Engineering*, especially for a course with lecture on mobile robotics. More information about the project can be found on the project website `https://www.ai-engineer.de/` and in [11]. Our goal is not only to offer criteria on choosing mobile robots for educational purposes but also to offer a detailed step-by-step procedure of the whole selection process, as well as an exploration of its practical application through a real-world example. This distinguishes the paper from existing works. Therefore, our **main contributions** can be summarized as follows:

- providing 15 relevant criteria for the selection of an educational robot
- presenting a step-by-step guideline for the selection process
- including a case study to illustrate the application of this process

Our paper begins with an overview of relevant research directions in Section 2. Then, we describe a guideline for the selection process in Section 3. Afterwards we introduce the assessment criteria in Section 4. Here, we discuss the criteria for our case study as well. In Section 5, we then move on to the selection of robots. We explain the search process, how to apply the selection criteria and the final choice of the robot. Finally, in Section 6, we present the conclusions of our work.

2 Related Work

The number of mobile robots for education has grown steadily over the years, as well as the papers written on the subject [5,19]. The broad selection of works on education and robots differ in their focus. Some present a specific robot [1,3], while others provide an overview based on criteria for a variety of robots [5,7,17], some have a very specific focus, e.g., social robots [10,15,21] or purely mention the criteria for selecting a robot [4]. Even when papers mention selection criteria, they often lack comprehensive descriptions or fail to provide justifications for their relevance. In addition, the number of criteria and robots considered varies greatly. For example, [19] mentions four essential criteria, [7] goes into details on six criteria and ten robots, whereas [2] identifies 83 attributes of robots. Furthermore, [2] only considers manipulators and thus makes a restriction. There exist several categories and classifications of robots. Robots are categorized as stationary, land-based, air-based, or water-based [18]. Another straightforward classification is by type of locomotion (manipulators, legged mobile, and wheeled mobile robots) [1]. There are other categories in further papers, e.g., based on the difficulty of programming [5] or classification based on the set-up, such as assembled, do-it-yourself (DIY), pre-built, and others [4,12,20]. Given the vast number of categories available, we currently lack an overview of relevant categories for robot selection in education. Similar to [7], this paper aims to help selecting a suitable robot for education, based on a small number of important criteria. Our study differs from the works above in providing both comprehensive criteria for the selection of robots, as well as a step-by-step guideline for the robot selection process. We further supplement the guideline by a case study to enhance comprehension.

3 Selection Process Guideline

We describe seven steps of an educational robot selection process which are presented in Figure 1.

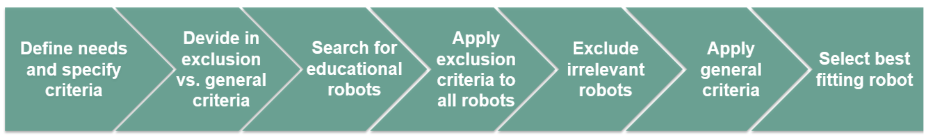

Fig. 1. Overview of the seven steps to select the best fitting robot for a specific educational use case.

1. First, we suggest **specifying** the different **criteria** for ones use case. This entails systematically addressing each criterion, describing any limitations or constraints.
2. In the next step one has to identify which criteria are necessary for meeting the requirements. It is essential to **differentiate** the criteria into **general** and **exclusion criteria**. The exclusion criteria thereby reflect the mandatory requirements to be fulfilled.
3. After the criteria are adapted to the use case, the **literature review** on robots starts. When conducting the literature review, we suggest employing both forward and backward searches within relevant publications, i.e., look into citing and cited publications, as well as conducting searches on the websites of relevant robot manufacturers.
4. Each identified robot should undergo an initial evaluation to determine if it **meets** the **exclusion criteria**.
5. In case a robot does not meet one or more exclusion criteria, we can **stop** considering this robot. This step swiftly reduces the number of robots under consideration, saving us a substantial amount of time.
6. If all exclusion criteria are fulfilled, we **check** the **general criteria** for the remaining robots. We propose **weighting** of the criteria if several robots fundamentally fulfill the requirements.
7. For the **final selection** of the most suitable robot we compare the advantages and disadvantages in more detail. This allows the remaining robots to be narrowed down further to one robot, that fits the requirements best.

4 Assessment Criteria

Diving deeper into our guideline, we address the first two steps in this section in more detail. In the following, criteria frequently mentioned in the literature for selecting robots in the education sector as well as the relevance are presented. An overview of the 15 criteria is visualized in Figure 2.

Fig. 2. Overview of all 15 assessment criteria

To enhance our understanding and significance of the criteria, we directly correlate them with our case study. As mentioned in Section 1, the case study focuses on choosing mobile robots for students in the *AI Engineering* Bachelor Programme.

1. **Price:** Mobile robots have a wide price range [12]. Many papers therefore mention the affordability of a robot as a criterion for selection [1,7,19,20]. The prices vary for different locomotion types due to their complexity, but the function also influences the price of a robot [1,7]. This implies that the price range imposes constraints on the selection of robots.
   Case study: In our case study, we have a budget of up to 6,000 € available to procure ten mobile robots. Accordingly, the price of the selected robot can be up to 600 € each.
2. **Purpose:** To choose a robot suitable for a specific purpose, one must consider the intended use of the robot. An initial distinction can be drawn between usage for research purposes or for education [1]. This is particularly relevant when the robot is intended for educational and research purposes, aiming to maximize its utilization [1]. However, above all, it is essential to identify which student group is the appropriate target, along with the skills, knowledge, and learning objectives that the robot aims to address [4,5,17].
   Case study: The mobile robot should be suitable in higher education teaching for bachelor students in the 5th Semester. Nonetheless, robots used for research are not directly excluded because they may also fulfill the other criteria. Above all, the criterion is connected with software development, as the robot must offer higher programming languages.
3. **Category:** The category refers to the type of locomotion of the robot. In [18] a very detailed description of the various possibilities is presented. A

limitation may be given by the teaching environment, e.g., using drones inside small classrooms can be rather critical, and year-round teaching outside is only possible in some places [7].

Case study: For us, it is essential that robots are to be used in classrooms. This therefore excludes all robots that are not land-based. Since we want our students to learn localization and navigation techniques we need mobile robots.

4. **Release date:** In various papers, the release date is also mentioned as important when comparing robots [17,1]. The date indicates different aspects. For instance, an older release date may suggest that the robot is no longer aligned with the current state-of-the-art technology. Additionally, it is possible that the robot should be excluded from consideration because it is no longer in production [19].

   Case study: We only consider robots launched on the market in the last four years. This also increases the likelihood of finding up-to-date training materials for the robot.
5. **Kit type:** The kit type refers to the state in which the robot is delivered. There are a lot of different categorizations [4,12,20]. Depending on which type is selected, the students need different skills [19]. For example, a robot that needs to be assembled may require tasks such as soldering cables. Another aspect influenced by the kit type is the cost, as DIY robots are generally cheaper than fully assembled robots [7].

   Case study: For our purposes, we have made a separate categorization based on needs. As the focus is on teaching computer science and artificial intelligence, DIY kits that require soldering should be excluded, as this step takes too much time and is no learning goal. Accordingly, DIY kits were divided into two categories: soldering and non-soldering. Furthermore, pre-assembled and assembled were used for classification, whereby pre-assembled includes customizable kit types due to their design, and assembled means that they are delivered ready to use.
6. **Availability:** Availability is a significant limitation since some robots are only available in certain countries and are not intended for the global market [7]. Therefore, when selecting a robot, it is essential to consider whether it is available for purchase in the desired country. The release date also plays a role in the availability of robots.

   Case study: Availability is an essential requirement; otherwise, we cannot purchase the robot. Robots for which it was unclear whether they are available in Germany are excluded from the selection.
7. **Software development:** Particularly when utilizing the robot for teaching programming or more advanced subjects, careful consideration must be given to the suitable level of complexity in the programming language [4]. Visual programming languages, e.g., are a good introduction to programming [5]. However, some robots offer both basic languages and high-level languages [5]. Also the support of the Robot Operating System (ROS) [16] can be a criteria.

   Case study: For our case study, higher programming languages must be available as the robot is used in university teaching with experienced programmers. Preferably, it should be possible to program with Python since artificial intelligence tasks can then be implemented easily.

8. **Size:** Even though size is not often specified as a criterion, it is still one criteria to consider when selecting a robot [1]. Some considerations need to be made about the size of the robot: How many robots are needed? Is the room sufficient for the number and size to work with the robots without being restricted? How will the robots be stored when they are not in use? Or need the robots be transported regularly to different locations?
   Case study: The 10 robots will be used in the university rooms simultaneously, so the robot size should be accordingly. It should also be possible to store them in a cupboard when not in use. Smaller, mobile robots are therefore more suitable.
9. **Interface:** The interface refers to the robot's connection options with other devices. There are not only many different possibilities but also a lot of requirements that need to be met. Considerations should therefore be made in advance [1].
   Case study: Wireless transmission options, preferably WiFi, are desirable for the interface. The advantages of WiFi are, on the on hand, that most devices are WiFi-capable and communication would therefore be simple and, on the other hand, it has good transmission in speed and range. Although the interface is an essential factor in the selection process, it should not lead to exclusion from the outset.
10. **Open-source software:** Open-source software offers students, but also teachers, a significant amount of freedom to develop their ideas and adapt them to their needs [1,4]. However, this is not always necessary and depends on the desired purpose of the robots.
    Case study: Open-source software is seen as a positive feature because it offers various advantages for the depth of usage.
11. **Expandability:** Extending the robot with different components enables a broader range of applications [4,7]. This, in turn, can also be an advantage for maintenance or re-usability.
    Case study: It would be beneficial for us to expand the robot and thereby broadening the scope of use cases. However, expandability is also related to the existing sensors, actuators, and platform features.
12. **Platform features:** Different aspects of a robot's platform features can be considered in more detail. For example, as in [7], these can include the processing power, the number and type of sensors, the microcontroller, or the software deployment. Another feature can be the battery. The corresponding runtime should be achieved depending on how long the robot is in use. Depending on the importance of the various features, these can also be listed as individual criteria.
    Case study: Information on the microcontroller and the battery were mainly taken into account. For the battery, in particular, the running time should be at least that of a 90-minute lesson, but ideally 180 minutes.

13. **Sensors and actuators:** The choice of sensors and actuators varies widely and is largely dictated by the specific requirements of the use case. The greater the number of different sensors and actuators in a robot, the more varied tasks can be designed [4,14]. Possible sensors and actuators can be cameras, microphones, environmental sensors, loudspeakers, LEDs, or screens [14]. However, it is important to note that if the robot can be expanded, upgrading sensors and actuators is also feasible.
    Case study: As a focus is on applying artificial intelligence like object detection, the robot should provide the corresponding sensors and actuators. The presence of a camera or the ability to add one is significant for our use case.
14. **Educational material:** The availability of educational material is viewed critically [20,6]. Educational materials can vary greatly in appearance. Therefore, in case educational material is available, the quality and suitability, e.g., the language, depth and quality, should be examined more closely [7].
    Case study: It would be useful if teaching materials are available, but it is not an explicit necessity.
15. **Maintenance:** The purchase of robots is usually always associated with considerable costs. Therefore, and for sustainability reasons, maintenance should also be considered in connection with the selection of robots [7]. Information on the availability of spare parts or the possibility of repair should be taken into account as well as the robustness of the robot.
    Case study: Information on the replacement of parts or repair services was rated as advantageous. However, the robot should not be excluded if no information was found.

The criteria for selecting a robot generally have varying degrees of relevance depending on the specific use case. Some criteria must be met, as this is the only way to comply with the mandatory requirements. These criteria ultimately belong to the exclusion criteria, as they exclude robots from further consideration. For example, a frequent exclusion criterion may be price, as there is often a price limit given [7]. All criteria that do not have to fulfill explicit requirements or whose fulfillment is not of great importance can be classified as general criteria. This categorization allows us to narrow down the robots quickly so that we only have to look closely at those suitable for the specific application. In our case study, seven criteria are mandatory for our purpose. As these represent a restriction, we have defined these criteria as exclusion criteria. A summary of these criteria are presented in Table 1.

5 Robot Selection

Up to this point we have reached an understanding of the selection criteria. As shown in Figure 1, the process from the the specified selection criteria to identifying the appropriate robot encompasses five more steps. These steps will be comprehensively explored in the following, again with the aid of our case study to provide a practical illustration.

Table 1. Exclusion criteria for our case study

Criteria	mandatory requirement
Price	not more than 600 € per robot
Purpose	suitable for university teaching
Category	land-based, mobile
Release date	less than four years
Kit type	no DIY kit with soldering
Availability	available for purchase in Germany
Software development	higher programming languages possible

5.1 Search for Educational Robots

The search for educational robots is step 3 in our process. For this purpose, forward and backward searches were carried out within relevant publications, which allowed us to compile a comprehensive list of robots. During the literature research we conducted keyword searches using terms such as educational robots, educational floor robots, and mobile floor robots in education. Well-known manufacturer websites were also searched. It should be noted that the search already considered that the robots are mobile land-based robots. This is due to the fact that the category land-based and mobile are exclusion criteria. By incorporating these criteria directly into the search, we significantly reduce the number of search results. In general, we recommend including exclusion criteria into the search to receive better fitting search results and minimize time applying the criteria in the next step. A total of 56 robots were found through our research. These included robots from well-known manufacturers like *fischertechnik* as well as robots from small start-ups such as *Learning Robots*. Accordingly, a diverse selection of robots was found. We utilized a spreadsheet to enter the robots and the associated criteria, facilitating a more in-depth analysis of the robots.

5.2 Applying the Exclusion Criteria

All 56 robots were finally evaluated using our seven exclusion criteria in Table 1. Please note that for other use cases one could have different exclusion criteria. The manufacturer's websites were accessed to look for the desired information, as well as product data sheets or various publications on the individual robots. For some robots, it was not possible to clearly determine whether they were available to purchase in Germany. Furthermore, many of the robots were introduced more than four years ago, or their price exceeded our limit. Accordingly, the three criteria of availability, release date, and price were the most restrictive. It should be noted that these three criteria were usually the quickest to identify. Only four robots were rejected due to soldering during assembly, and most robots had a wide range of uses. Rarely, however, robots are rejected due to software development. On the one hand, many of the robots offered different programming languages; on the other hand, it should also be noted that as soon as one of the criteria was not met, the others were not taken into account, since these criteria lead to a direct exclusion of the robot. Finally, for our use case 49 robots were excluded based on our exclusion criteria. The next step is then to apply the general criteria to the remaining robots.

5.3 Applying General Criteria

In contrast to the exclusion criteria, where the robot was no longer considered as soon as one criterion was not met, all general criteria are considered for the remaining robots. We applied the general criteria to the following list of seven robots in our case study:

1. **Robotics Hightech** from Fischertechnik (`https://www.fischertechnik.de/de-de/produkte/spielzeug/robotics/559895-robotics-hightech`)
2. **iRobot Create 3** from iRobot (`https://edu.irobot.com/`)
3. **Thymio II** from Mobsya (`https://www.thymio.org/`)
4. **Bittle** from Petoi (`https://www.petoi.com/products/petoi-bittle-robot-dog`)
5. **AlphAI** from Learning Robots (`https://learningrobots.ai/`)
6. **Finch Robot 2.0** from BirdBrain Technologies (`https://www.birdbraintechnologies.com/products/finch-robot-2-0/`)
7. **RoboMaster S1** from DJI (`https://www.dji.com/de/robomaster-s1`)

Finally, the criteria were weighted to narrow down the robots further. For example, WiFi was preferred for the interface, as some robots offered this; those that did not were sorted out. Furthermore, the possibilities offered by open-source software were seen as a significant advantage, which not all robots fulfilled. One could also use a mathematical model to weight the different criteria, e.g., by taking a weighted sum over the criteria. But we believe that decisions should be made eventually by humans and with sensitivity and therefore we do not employ such a procedure.

The two robots that best met our requirements are the *iRobot Create 3* [9] and *Bittle* [8] (see Figures 3 and 4). Let us introduce both robots in more detail:

– **iRobot Create 3:** iRobot mainly manufactures vacuum and mopping robots. As the appearance of the iRobot Create 3 suggests, it is based on the basic structure of one of the vacuum robots. It is also not the company's first educational robot but a further development of the second

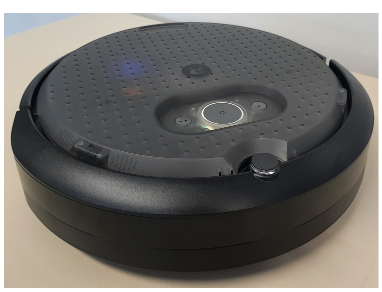

Fig. 3. iRobot Create 3 (own illustration)

Fig. 4. Bittle from Petoi [8]

version. iRobot Create 3 has not only various programming languages but also open-source software. Another advantage is the expandability of the hardware, as this allows, e.g., a camera to be added, which can be used for computer vision applications. However, the robot also offers many built-in sensors and actuators, such as six IR obstacle sensors, a downward optical flow sensor for odometry, a loudspeaker, six RGB LED rings, and many others. In addition, iRobot provides a learning library with various tutorials and possible example tasks.

- **Bittle:** The robot Bittle, as shown in Figure 3, is a robot dog and therefore a quadruped robot. Petoi produces robots exclusively for playing and learning. The Bittle robot is based on an Arduino platform designed to be as lifelike as possible. The robot offers three different programming languages, two of them are high-level. It also has open-source software, and its hardware can be expanded. The expandability is particularly important as the robot does not have many sensors and actuators. However, many extensions are available. For example, the *Basic Sensor Kit* includes a light sensor, touch sensor, gesture sensor, and others, but a camera can also be purchased separately. Petoi also provides free downloadable curricula.

5.4 Select Best Fitting Robot

Once all criteria have been applied the remaining robots have to be compared to find the most fitting. We reached the final step of the selection process (see Figure 1). In our case study, the selection has been made so that there are two robots to choose from. Now we compare the two remaining robots for their advantages and disadvantages. For our application, an advantage of the iRobot Create 3 is that it is suitable for the already existing examples of a vacuum cleaner in our lecture. The functionality of such a robot is also discussed in more detail in the existing material. The Bittle, on the other hand, has a different mode of locomotion due to its design as a quadrupedal robot, although this may be quite exciting to program. Then again an advantage of the Bittle is that it is much cheaper than the iRobot Create 3. For both robots we would have to expand the hardware, although Bittle, has fewer sensors and actuators for our purposes. The iRobot Create 3, on the other hand, could initially be used without expanding the hardware, but even with the addition of a camera, it would still be within our price range. Another advantage that both robots have is the availability of spare parts from the manufacturers. Ultimately, we opted for the iRobot Create 3, as it fits better into our classroom use and has more advantages.

6 Conclusion

The paper presents a step-by-step guideline that describes the selection process for a suitable robot for education. Not only are 15 relevant criteria for selecting educational robots presented, but a case study also illustrates the whole selection process. The criteria presented relate generally to use in education, so depending on the specific purpose for which a robot is being sought, a specific criterion can be added. Nonetheless, varying usage requirements can be addressed by the selection of exclusion criteria and weighting of the general criteria. Overall, the step-by-step guide can be utilized to find a fitting educational robot based on needs. It stands out from the previous work by guiding the entire selection process.

Two aspects that warrants further elaboration is first the lecturers evaluation of the purchased robot and second the practical use of these robots in educational settings. Building upon this foundation, the guideline could be expanded to encompass a comprehensive journey from the initial robot selection to its effective integration into a classroom or lecture environment. In conclusion, through the utilization of our guideline, we offer a structured framework to assist in selecting a robot that aligns best with the educational setting.

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