Maximising the Effectiveness of Educational Robotics through the Use of Assessment for Learning Methodologies

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Abstract. Like all tools, educational robots are only as effective as our skill in using them. We consider the methodologies grouped under the heading of Assessment for Learning (AfL) as a summary of best teaching practice. This paper explains how AfL and educational robotics[a] form a symbiotic relationship that can truly enhance a student's learning experience. It reviews AfL methods and shows their natural empathy with ERA Principles and how to adapt them into lesson plans featuring educational robots. This theoretical analysis is supported by classroom observations where teachers have applied these ideas to their use of the Roamer® robot.

Keywords: Educational Robots, Assessment for Learning, AfL, Formative Assessment, Assessment of Learning, AoL, Roamer®, Best Teaching Practice, ERA Principles, Teacher Training.

1 Introduction

The preoccupation of politicians, press and public with school performance puts the topic of assessment at the top of most educational agendas. Every election we hear politicians promising educational reform that will raise standards. Crudely put, government concern focuses on a bean counter question: we put this into schools, what do we get out of them? They answer that through testing. In recent years, this term has become "high stakes testing", which indicates the importance to the school and student on how well they perform.

According to professors Paul Black and Dylan Wiliam of Kings College, London[b], this focus on input and output treats what goes on inside the school and the classroom as a black box. In a 1998 seminal paper "Inside the Black Box: *Raising Standards through Classroom Assessment"* [1] Black and Wiliam pointed out the importance of assessment within the school, classroom and lesson. This type of assessment informs teachers and students about their performance with a view to managing the lesson in a way that aims to improve the quality of the student's learning experience. Following

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[a] I use the term Educational Robotics to mean teaching with robots. Robotics Education focuses specifically on learning with robots.

[b] Black has now retired and Wiliam is at Princeton.

this work, Black, Wiliam and others [2], [3], [4], [5], [6] have developed assessment methods which a teacher can adopt as part of her teaching practice. This work has become known as Assessment for Learning (AfL).

This paper reviews the ideas and practices of AfL. I explain how to apply AfL methods to educational robotics based on selected observations made across a wide range of age groups while implementing STEM based activities using Roamer® across a wide range of age groups in the UK and USA. Throughout this narrative, I will refer to the ten ERA[c] Principles [7]. It will, I believe, reveal an empathetic relationship between AfL and ERA.

Traditionally constructionist ideas provide a theoretical basis for the use educational robots. However, it appears there is a significant misunderstanding on the nature of constructionist based teaching practice. The chequered history of using this psychological theory in the classroom partly explains this problem [8]. The philosophical and political polemics constantly challenge constructionist practice, on which the acceptance of educational robotics depends. I believe that understanding and applying AfL methodology to educational robotics will ensure that this technology can correct some of these misunderstandings. This is essential if the effective use of educational robots is to become common practice within schools.

1 Types of Assessment

Table 1. Types and aims of Assessment [9]

Category	Type	Purpose
Assessment of Learning (AoL)	Evaluative	Monitoring national standards
		Make educators and politicians accountable
	Summative	Provision of information to universities and employers
		To determine students continuing education
		To report achievement to students and their parents
Assessment for Learning (AfL)	Diagnostic	Supporting students by diagnosing their difficulties
	Formative	Supporting student learning through feedback

Our focus is primarily on the Formative aspects of AfL. Diagnostics has a role and undoubted potential in maximising the effectiveness of educational robotics. However, this requires more research and this article restricts itself to the Formative aspects of AfL.

2 Teachers and Teaching with Educational Robots

Educational robots evoke creative environments. Suddenly a student grasps an idea – perhaps not in the way we expected, perhaps not the idea we listed in the lesson

[c] ERA – Educational Robotic Applications

objectives. Nevertheless, the lesson is exciting, thrilling and everything we would like to achieve. For over 30 years I have observed many teachers, using Turtle and Roamer® robots, face these dynamic situations. They cannot prejudge the spontaneity of the scenario. Yet, their ability to respond positively and manage this situation is crucial. They can kill it or help it to thrive.

In a keynote address to the Association for Learning Technology, Dylan Wiliam discussed an American trend for scripting lessons [10]. This step-by-step approach, written by experts, literally had lines like, "Now walk around the classroom". If teachers unwaveringly followed the instructions a perfect lesson would result – guaranteed? Wiliam's audience laughed at the idea. He argued that chaos theory was necessary to describe even the best organised classrooms. Small difference between situations could lead to dramatically dissimilar outcomes. Perhaps a student had argued with a parent before school; perhaps they had read something the night before that would give them a vital insight. Perhaps they missed breakfast. Like the flapping of a butterfly's wings causing hurricanes, these and many more seemingly innocuous things can radically alter the classroom experience.

I have been involved in many after school projects, where parents or people with particular expertise engage with students in a quasi teaching role. One such example was a Neighbourhood Engineer Scheme where professional engineers helped students study design technology. It was clear that while the engineers had great technical expertise, they lacked teaching skills. In one such incident, students made small buggies and rolled them down a ramp. The challenge was to build a buggy that would travel the furthest from the bottom of the slope. While most vehicles travelled at least 3m, one student's effort travelled a couple of centimetres. Seeing his embarrassment one of the engineers went to help. In such circumstances, a teacher would question the student about their design. They would support him, but ensure he did the work improving his design. This would be an opportunity for the teacher to engage the student with the science embedded in the activity. The engineer fixed it for them. The engineer missed the educational potential of the scenario.

I personally marvel at a teacher's ability to, not just cope, but in many cases to create spectacularly inspiring lessons. I have no hesitation in proclaiming that teachers need to be at their best to make the most effective use of robotic technology. What quality do such practitioners possess, can we identify it, and can we pass it to others – after all our students deserve the best. Carr [11] argues, that good teaching is not merely technique; it is an art and requires talent. Yet, Professor Michael Howe advocates even an inherent genius requires a combination of environment, personality and sheer hard work to realise their potential [12]. Simply put, practice makes perfect.

So what is involved? Can we identify these skills and arts, are they pertinent to teaching with robots and if we can identify them, how can we transmit them to teachers without creating a script?

I have already cited one of many situations where non-teachers meet students in a learning environment. In fact, it is wrong to assume that all people employed as teachers are trained and qualified [13]. Often lack of trained instruction predominates in poorer, ethnic communities – communities which can derive significantly from the use of educational robots. Even excellent teachers need to understand how to apply their skills to get the most out of educational robots. The thesis of this paper is that the methods of AfL offer a way to resolve some of these issues.

3 Introducing AfL

"What is the aim of education?" Since ancient times this question invokes two basic answers. According to Plato, people should be educated for their role and service to society. Aristotle argued that education should "bring out the good in people". There was a caveat to his belief, captured in the aphorism, "Look after the pennies and the pounds look after themselves". By achieving their best people will take care of society's needs.

I feel this sentiment is directly applicable to educational robotics and AfL. The ERA Curriculum and Assessment Principle allude to the tripartite interactive relationship between student, robot and teacher. The quality and nature of these interactions provide natural opportunities for AfL practices. If we tend to these efforts with sufficient care, good assessment for learning results will largely take care of itself. So what is AfL?

Dylan Wiliam gets to the heart of the issue when he states, *"An assessment activity can help learning if it provides information to be used as feedback, by teachers, and by their students, in assessing themselves and each other, to modify the teaching and learning activities in which they are engaged. Such assessment becomes 'formative' assessment when the evidence is actually used to adapt the teaching work to meet learning needs."* [14].

The processes of ERA interaction and AfL feedback share a commonness of purpose. Despite the capricious nature of the student's responses, AfL techniques offer teachers a way of addressing the problems. They represent good teaching practice. In fact, they form a set of guidelines derived from good practice. By writing activities formulated on these guidelines and encouraging teachers to assiduously adopt these approaches, we aim to ensure the effective teaching with robots.

4. AfL Methods

AfL consists of four essential elements:

1. Learning Intentions
2. Success Criteria
3. Quality Interactions and Feedback
4. Peer Assessment

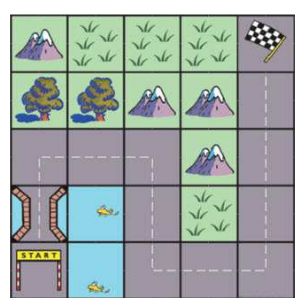

Figure 1: The Robot Rally Race Mat

In exploring these tenets, I will refer to a Roamer® activity called the Robot Rally Race[d]. In this activity, the students have to determine the fastest route for the robot to get from a start to a finish. The robot travels different speeds over the different terrains. The tasks involve students in determining speeds via a series of experiments and then using their data to calculate the best possible route. The activity also provides an exemplar of the ideas involved in this paper.

4.1 Learning Intentions

Do not confuse **Learning Intentions** with the Learning Aims or Objectives of a lesson. A learning intention is a student perspective. What do they think is expected of them? In the Robot Rally Race, the first learning intention is "I am learning how to establish the speed of moving objects". Notice a learning intention is about what the students will learn, not about what they will do. It is not, "We are calculating the speed of Roamer®…" It is also useful to de-contextualise the intention. This helps make the real learning clearer to the student and helps with the transfer of the idea to other situations.

The teacher has to establish the learning intention by negotiation. It is not a matter of writing up on the blackboard the learning intention, but getting the students to express the idea. Typically, the teacher would discuss the problem: "Getting the Roamer® from start to finish in the fastest possible time". "What do you need to know to be able to determine that?" "How are you going to establish the speed?" The teacher could just tell the students, "You will need to find the speed of the Roamer® over different terrains. You will do this by…" The negotiation approach radically transforms the nature of the student experience. When it is something that they are deciding to do, they become more engaged and more importantly, it becomes clear to the teacher what they do or do not understand the task and the ideas involved. It is better and more efficient to clarify misunderstandings before students spend a lot of time doing the wrong thing.

In a constructionist jargon, teachers refer to this as "students deciding what they will learn". Opponents of constructionist teaching talk of this approach with incredulity. "Students should be taught what the teacher decides they must learn!" This totally misunderstands the subtly of the situation. In his famous self help book, Dale Carnegie cites the technique, "Let the other person feel the idea is his or hers are you missing a word here, David?" [15]. This negotiation aims to achieve this. To me it is the scary part of teaching. It is not a typical Carnegie scenario of one on one. It is one teacher and 20 or 30 students. Teachers have techniques for managing this situation, many of which are empathetic with Carnegie's maxims: ask questions instead of giving direct orders, don't embarrass the student, praise every improvement, encourage, make faults seem easy to correct, make the student feel happy about following your suggestions, praise with honest appreciation and student's efforts? Does this make sense and if they make a mistake deal with it indirectly. So

[d] The activity is copyrighted by Dave Catlin, et al and is available under a Creative Commons Licence. Access is available to guest visitors to the Roamer Activity Library via www.valiant-technology.com

for example instead of, “That’s wrong, what you need to do is…”, teachers will ask the other students whether they agree or do they have a different idea.

The learning intentions of the Robot Rally Race are straightforward. This is not always the case. Students might suggest something that will take them in a “wrong direction”. Is it worth pursuing, will the student learn from their mistakes? With some educational robotic activities, teachers can face situations where students come up with extremely creative and unforeseen ideas. Since the development of creativity is one of the advantages of educational robotics, it is not a good idea to suffocate it at birth for sake of “keeping to plan”. Nevertheless, there is no hard and fast rule of how to deal with these situations; it is a matter of the teacher’s professional and personal judgement. In a non-robotic activity, one teacher I know had a semester’s work planned when a student found a Roman coin in a local field. This generated such excitement amongst the students he decided to harness their enthusiasm and re-planned his lessons using the coin as the catalyst. He more or less covered the same curriculum, but had a lot more work to do. He judged that the advantage of teaching enthusiastic students was worth his extra effort.

A precept cited in a lot of AfL literature is to keep to one learning intention per lesson. This is not practical or even desirable in many educational robotic activities. The Robot Rally Race activity splits into several steps. The first task establishes the speed data, and the second uses the data to determine the best route. The third relates to the time trials and the final step analyses the collective data gathered from the entire activity. The breaking up of activities into manageable chunks is the well known process of scaffolding [16], [17][e]. This gives teachers a powerful method of personalising the activity. They can “chunk” the problem up or down to suit the ability of their students.

4.2 Success Criteria

How does the student know when they have been successful? As with learning intentions, the teacher should negotiate success criteria with the students. “How will you know when you have achieved this?” “What will you need to look for to know you have completed the task?” In the Robot Rally activity, acceptable success criteria for the first part of the task could be “We will complete this when we have enough data to solve our problem”. This example is straightforward. Other examples are not as simple. For example, a popular activity with Classic Roamer® was to turn Roamer® into a dog. What does a robot dog look like? How does it behave? This type of open ended task requires a different approach. Since most robotic activities are part of group work, success criteria might be “When we have designed a robot dog that we all like”.

Success criteria should not simply reward learning intentions. “I am learning how to establish the speed of moving objects”, should not become “I know I am successful

[e] A lot of work remains to better understand how to construct activities involving the application of Vygotsky’s idea of ZPD and how this applies to the notion of scaffolding activities. See reference [17] for a brief review of the background to this work. I use scaffolding as simply the breaking up of the activity into practical steps manageable by the students.

when I can establish the speed of a moving object". Instead, it might be "I will be able to explain to the rest of the class how to establish the speed of a moving object".

A description of what they are doing and why they are doing it, is frequently a very powerful and practical way for students to realise the progress of their learning. This is another hallmark of an often misunderstood constructionist idea – students taking responsibility for their learning. In trying to explain a process or use the robot to demonstrate an idea, students know how well they understand what they are talking about or doing. AfL creates a culture where students have the confidence to acknowledge their struggles and ask for help. In this sense, students become responsible learners.

Demonstration and process explanation are natural outcomes of educational robotic activity. When students engage in these tasks, they quickly come to grips with the limits of their understanding, generally in a way that is positive and non-threatening. Moreover, students do not limit their discussion to what they have done, but frequently talk about what they would like to have done, why they did not do it, problems they could not resolve, or how they would change it next time. All of this is "gold dust" to the alert teacher trying to discern the status of a student's progress.

Although you normally establish success criteria at the start of a lesson there are times it is better to allow the notion to emerge from the activity. An argument that defining the nature of success at the start of the activity limits creativity has some foundation. In our dog example, we could review the outcome when the students have completed their task. "Are the students satisfied with their work?" "Do you think they put a fair effort into the task?" "What do other groups think about it?"

4.3 General Comments on Learning Intentions and Success Criteria

It should only take a few minutes to establish the learning intentions with a class. While their ascertainment really provides an excellent foundation to any educational robotic activity, setting them up should not become a formulaic mechanical process. The ERA Principle of Pedagogy identifies 28 characteristics of educational robotic activities. One of these called a "trigger"[f] provokes students into discussing and describing something Roamer® did. In this case defining learning intentions would "spoil the party".

Once the students have clearly expressed the learning intentions and success criteria, teachers find it useful to ask the students to record these on a blackboard or Interactive White Board. Making them visible acts as a reference point throughout the activity helps to keep students on task. The teacher can reference the statement to help keep them focussed.

4.3 Feedback and Quality Interactions

During a lesson, how does the teacher know that the students comprehend what she is saying? If they don't understand, should she just continue in the vague hope that

[f] Originally labelled "provocateur".

“the penny will drop” magically, mysteriously at some time in the future? A teacher needs to constantly readjust her teaching in response to her audience. Activities need to present the opportunity to generate “feedback” charting a student’s status and progress. The teacher needs to be receptive to this information. Deputy head Anne Butler from Hatwells Primary School in Bristol, England was involved in setting up an AfL process in her school. She noted, “*It was only when I allowed myself to stop teaching and gave my time over to observing and really just to sit and watch and listen to a group of children that I noticed there were significant differences in the way children used mathematical language*”. Teacher Peter Glanville from the same school declares how checking student workbooks had deceived him into thinking they knew a particular topic. When they came to do some practical work, he realised the limitations of their understanding.

Educational robotic activities provide situations where teachers can watch and listen to students coming to grips with knowledge. Literally, she has time to walk around and observe. She has the time to think about how to manage the various situations. Should she intervene just with the group, or is there something of value to share with the whole class? Educational robots create these opportunities all the time.

Teacher observations are one strand of this process. What about the student? AfL encourages the creation of a classroom culture where students feel comfortable with admitting they don’t know or feel confused. A carry over from the philosophical basis of Logo, the notion of debugging solutions makes a vital contribution to the establishment of an effective learning environment [19]. The practical context of the activities tends to create partial solutions; prototypes and work-in-progress they are all acceptable stages at which a student’s learning becomes apparent, both to them and to the teacher. Often this feedback immediately impacts a student’s search for improvement and refinement. “My solution did not work. What do I do to fix it?”

A good interactive process is not about marking in terms of grades but in terms of comments. This approach has to strike a balance between students recognising what is good about their work, as well as what is necessary to improve.

Many AfL practitioners adopt a traffic light communication system. If the group feels confident and believes they understand what they are doing, they display a green card. If they feel a bit confused, they show a yellow card, and if they are really stuck, they display red. When engaged in a whole class discussion teachers can ask students to display their understanding through this semiotic[g]. This allows the teacher a snap shot view of the class. It also is useful for students working in groups. The students can continue to work, but display their status. This allows the teacher to identify how to distribute her time.

The other aspect of this section is quality interaction. We touched on this when discussing the establishment of learning intentions and success criteria. This area of a teacher’s skill falls under the guidance of “effective questioning”. One consistent tip on obtaining quality feedback is to allow students think time, before you expect them to respond.

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[g] Another method, more applicable in a whole class survey is to use thumbs up for confident understanding, thumbs down for confusion and thumbs in between for uncertainty.

A particularly useful approach splits an activity into radically different tasks. Each team sends a student to a group who investigates one aspect of the project. They then return to their team bringing that skill with them.

With educational robotics, quality interactions can take place in many innovative ways. In one Roamer® project, groups were working in different teams. The students found that one group of girls had a particular expertise needed by the others. Accordingly, they decided to share that expertise amongst the rest of the class and arranged a "sub contract". Ad hoc interactions between students create powerful learning scenarios. They are not something you can plan or force; nevertheless experience has repeatedly shown that educational robot activities generate these scenarios on a regular basis.

4.4 Peer Assessment

The last section began to highlight the natural interactions between students. Black and Wiliam showed that students were more likely to challenge each other's judgments of their work, thereby sparking discussion and debate. They can do this peer to peer in a way that teacher to student cannot do. Frequently robot activities culminate in a public event, where groups bring their work together and discuss and compare. In the Robot Rally Race, there is a time trial as each group tests their chosen route. This is straightforward. In other activities, a solution is not so clear. In these circumstances, it is possible to create debates, where groups can explain their ideas and answer criticisms and listen to praise. This approach gradually builds a student's sense of quality. It is not just simply the students listening to comments about their efforts. An important aspect of this is students learning how to appraise the work of their classmates. This situation encourages students to engage their explicit knowledge

5 Conclusions

This paper is a preliminary review which I believe demonstrates the affinity between AfL methods and educational robotics. In trying to establish a regular role for educational robots in the classroom, it is essential that we create activities that showcase a robot's positive attributes. Poorly designed and/or badly managed activities have the ability to bring magical lessons into the same old drudgery.

I believe AfL methods will guide the development of skills required by teachers to effectively use the technology. It is clear to practicing teachers that AfL methods are not particularly new. It is what good teachers do and have done for many years. In a Robotic Performing™ Arts Project, a teacher looked at our lesson plans. Some things he used, others he did not. His substitute actions were, however, a reflection of AfL ideas. Unlike scripted lesson plans, we can only regard robotic activities (even one full of detail) as aide memoirs and a loose plan. They provide a framework that teachers can use, but should not be slaves to. In the end the teacher has to make the judgement – are the students learning and what is the quality of that learning?

As we have discussed, at this stage we have the students and the teacher as intelligent players in the tripartite relationship. In the coming years, robots will grow in capability. Now is the time to gather data on interactions, and I believe the AfL offers a structure to organise this process.

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