Placemat Instructions for Open-Ended Robotics Challenges

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Abstract. This research documents our investigation of alternative forms of written instructions for robotics education. Currently, instructions that accompany educational robotics kits often provide students with step-by-step directions leading them to one "correct" solution. This research explores alternative forms of written instructions called placemat instructions. Placemat instructions are a one-page (double-sided) representation of an open-ended robotics challenge. They give students a few images of example builds and some code snippets to get them started, but they do not provide step-by-step instructions or dictate the creation of a single solution. The goal of this study is to investigate what type of learning experiences unfold when placemat instructions are used to facilitate open-ended robotics challenges in K–12 classrooms, and how these learning experiences differ from those when no placemat instructions are used. We analyzed classroom video data to look for ways students did or did not use the placemats, where students became stuck or required the assistance of a peer or instructor, and the time it took each group to reach an initial testable prototype. Based on these data, we found that the use of placemat instructions to support open-ended robotics challenges in an 8^{th} grade science classroom was successful in: (1) helping students quickly and easily get started with open-ended design challenges, (2) supporting students and teachers when questions arose during the activity, and (3) inspiring a diverse set of student-generated solutions to a problem.

Keywords: Educational Robotics, Learning Support Tool, Instructional Tool

1 Motivation

Research has shown that open-ended design-based inquiry is in some ways more effective than traditional lecture-based instruction [1]. K–12 classrooms have begun to incorporate more open-ended learning instruction combined with educational technology to empower their students to learn science, technology, engineering, and mathematics by doing instead of simply by watching and listening [2-4]. This has proven, in many cases, to have a positive impact on students' attitudes towards learning as well as their overall academic achievement [4]. However, there are many challenges that make open-ended robotics learning experiences difficult to implement [5-8].

In general, the problem-based learning environment is structured differently than a traditional classroom environment. This means that students and teachers are fulfilling different roles than they are used to in a more traditional learning setup [5]. This transition can be difficult for students, and it sometimes brings out coping behaviors that hinder their ability to extract full value from the learning experience. Some students assume a passive role and simply do not participate in the activity, or require frequent one-on-one support from the teacher. Other students engage in distracting and off-task behaviors, while still others seize control of the problem and refuse to cooperate with groupmates [6]. The different coping behaviors that students exhibit when engaging in problem-based learning puts added strain on the teacher as they try to motivate students, all with unique needs, to meaningfully engage with an open-ended task.

Teachers are also faced with adjusting to a new role during open-ended activities, as well as dealing with additional issues related to using robotics technologies with their students [6]. Lack of teacher training for the technologies being used, high student–teacher ratios, and poor classroom infrastructure are just some of the logistical challenges many teachers face when trying to use technology in classrooms [7]. Open-ended problem-based learning requires teachers to create different types of scaffolds and supports for students than are typically used [8]. Teachers understand that scaffolds are beneficial, and in some cases necessary, for students to be successful in a problem-based learning environment, but creating a scaffold that is useful without being too constraining is a major challenge. While using step-by-step instructions that come with many robotics kits might alleviate some of the challenges of using technology in the classroom, it eliminates the benefits of allowing students to come up with their own ideas and explore multiple solutions to one problem [9].

Finding this balance between showing and telling vs. inspiring and supporting is challenging, especially in a classroom context. Often times, any examples shown to students will wind up being internalized as a "correct" answer and be replicated by the majority of a class. Paulo Blikstein [10] describes his experience teaching students how to use a laser cutter. His introductory activity was to have students design and fabricate a personalized key chain. He was excited about the open-ended nature of the challenge, and while students did enjoy making their own keychains, they then became stuck on the idea that the laser cutter was only for making keychains and couldn't come up with anything else for which they wanted to use it. This "keychain syndrome" can happen with open-ended design challenges too [10]. As soon as students see one solution to a problem, even if they are told that they can and should come up with their own idea, it will be much harder for them to see outside of the initial idea that their teacher has presented. This is problematic, as the most important kinds of engineering and critical thinking happen when students stop trying to replicate the knowledge of others and start thinking for themselves [11].

The question then becomes: *What kinds of support resources for open-ended challenges can educators use with their students that won't hinder independent thinking?* Placemat instructions were designed with that purpose in mind: to help students get started and give them ideas (both for coding and constructing their robot), without dictating one "correct" answer. Educators and education companies have long been designing their own scaffolds for open ended learning in classrooms using robotics [12].

One example is the LEGO Subassembly Constructopedia which was a one-hundred page document providing inspirations and hints on building with the original LEGO Robotics platform (the LEGO MINDSTORMS RCX) [13]. However, despite the availability of these resources, research on teacher perceptions still shows that a lack of instructional resources is a major barrier faced by teachers trying to bring robotics into their classrooms [14]. While literature analyzing the benefits and shortcomings of using existing open-ended robotics scaffolds is limited, we believe that the placemat instructions are of a novel format and length and have the potential to lower barriers to entry for conducting open ended robotics challenges in the classroom. The goal of this study is to investigate what type of learning experiences unfold when placemat instructions are used to facilitate open-ended robotics challenges in K–12 classrooms and how these learning experiences differ from those where no placemat instructions are used. We are particularly interested in investigating how placemat instructions (1) facilitate students quickly and easily getting started with open-ended design challenges, (2) support students and teachers when issues or questions arise during an activity, and (3) inspire a diverse set of solutions to single challenge.

2 Study Design

2.1 Study Context

To investigate the impact that placemat instructions have on students participating in robotics challenges, we tested them in an 8th grade science class. The study site was a private school in the northeastern United States serving pre-kindergarten through 8th grade students. The study site has a six to one student–teacher ratio with an average class size of fourteen. Twenty percent of students receive financial aid and thirty-six percent of the student body are students of color. The study was conducted in four sections of an 8th grade science class, with each section containing between ten and fourteen students. All four sections of this 8th grade science class had previously used LEGO MINDSTORMS Education EV3 robotics kits as a data logging tool during their most recent physics unit. The LEGO MINDSTORMS Education EV3 robotics kit includes the EV3 Intelligent Brick, a small programmable computer that makes it possible to collect sensor data and control motors. The kit also contains LEGO Technic building components that students can use in conjunction with the EV3 Intelligent Brick, motors, and sensors to create their own robots [15]. For these physics activities, each pair of students built an identical car using step-by-step instructions that the teachers had provided. This group of students had not yet participated in any open-ended robotics challenges as part of this class, but they had done more open-ended projects with LEGO robotics in other classes. Each class block lasted forty-five minutes per the standard schedule at the study site. There were two different teachers for the four sections, each teaching two sections, and one observer taking notes and facilitating the video recording.

2.2 Activity Design

For this study, students in each section participated in two different robotics challenges. The first challenge was a “silly walks” challenge, where students were asked to build a robot that moves forward but does not use wheels as the main method of locomotion [16]. The second challenge was a “tug-of-war” challenge, where students were asked to build a car that could pull another car over a line. In two of the sections, one taught by each educator, students were given the placemat instruction for challenge one (silly walks) but not for challenge two (tug of war). The other two sections were not given the placemat for challenge one, but they were given a placemat for challenge two. Since it is impossible to ensure that each challenge is of the exact same difficulty/complexity, switching placemat assignment across the sections was done in an effort to help remove difficulty as a variable in the analysis of the efficacy of the placemat instructions. Each challenge lasted one class block (forty-five minutes). Students worked in groups of two with the same partner for each challenge.

The teacher of each class introduced the challenge to their students just as they would any other robotics challenge or activity. They briefly explained the challenge, the constraints, and then let students begin building. For challenges where students were given placemat instructions, the teacher passed them out with the LEGO MINDSTORMS Education EV3 robotics set and explained to students that the placemat instruction could be used as a reference if they wanted it, but could be ignored if they didn’t want to use it or didn’t feel they needed any help.

2.3 Placemat Instructions Design

The placemat instructions for each activity (shown in Fig. 1 and Fig. 2 below) were designed intentionally to be sources of inspiration without dictating a correct answer. The placemat instructions depicted three potential solutions. The hope was that students who didn’t want or need any assistance would simply bypass the placemat and proceed through the robotics challenge independently, naturally iterating and experimenting to produce a solution of which they are proud.

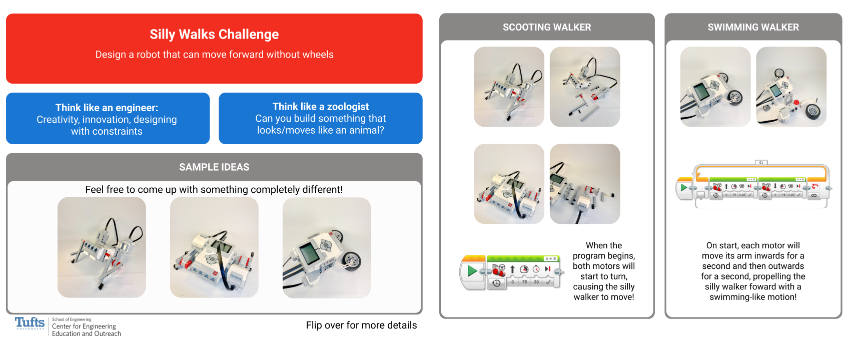

Fig. 1. Silly Walks Challenge Placemat Instruction (Left – Front Page, Right – Back Page)

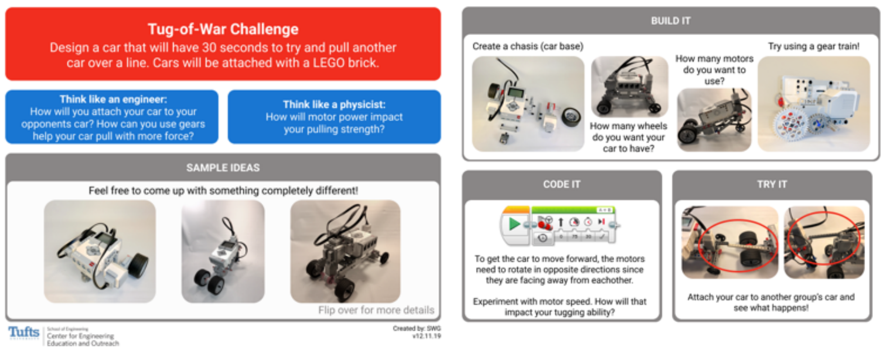

Fig. 2. Tug-of-War Challenge Placemat Instruction (Left – Front Page, Right – Back Page)

Students who just need a little help getting started or were simply looking for inspiration would be able to leverage just the front page (left-hand image in Fig. 1 and Fig. 2) to see some images of example robots and some tips for brainstorming ideas. For example, in the silly walks placemat, students were prompted to “think like a zoologist” and brainstorm ways that different animals move to come up with an idea for how to get their robot to move forward without wheels. For some students, the inspiration on the front page would be enough to get them started. However, some students may still feel lost or not know where to start with actually constructing a robot. The back of the placemat was therefore designed with those students in mind. The back page (right-hand image in Fig. 1 and Fig. 2) contains some example code as well as more in-depth depictions of example robots. Students could use these images to get started with building the robot from the picture. However, these images were intentionally small to make it possible, but challenging, to copy the idea exactly. The hope was that these images would get students started towards assembling pieces but then encourage them to have their own ideas and instead build a unique solution.

The power of using placemat instructions is that students have the agency to choose the level of assistance they want or need to use and when they want to use it. Realizing that some students will be more (or less) willing to take risks in their learning [17], we designed the placemat instructions so that students who are willing to engage in the open-ended challenges independently and with-out supports can do so by simply ignoring the placemat instruction altogether. Without the use of placemat instructions, the teacher would be the main source of support for any student needing assistance. The placemat instructions will hopefully act as another support system and alleviate some of the demand on the teacher during robotics design activities.

Methods

2.1 Data Collection

Each pair of students was video recorded as they completed the design challenges. There was also a camera placed in the front of the classroom to capture students as they collaborated with other groups and moved about the classroom testing their robot and asking the teacher questions. Photographs of the students' robotic solutions to each challenge were also taken. Additionally, one member from the research team was present during each class session to take field notes and facilitate the video recording.

2.2 Data Analysis

The video recordings of students working on the robotics challenges were analyzed and qualitatively coded. We looked specifically for instances when students referenced or used the placemat instructions and the impact it had on their learning experience. We also looked for situations in the classes where placemat instructions were not used and where students became stuck, frustrated, or required the additional assistance of a peer or instructor.

Additionally, we recorded how long it took students to create a testable prototype, and how much iteration they were able to complete in the forty-five minute class period. The goal of looking at this timing data is to see if the use of placemats helped students get started more quickly and therefore helped facilitate more testing and iteration in the same amount of class time.

While the study population size of approximately fifty students is too small for substantial quantitative analysis, the results below qualitatively describe the impact that the placemat instructions had on the learning experiences of this small population of students as they engaged in open-ended robotics challenges.

3 Results

4.1 Overall Results

The results revealed that the majority of students did not leverage the placemats at all (Fig. 3). Students that did use the placemats did so for a variety of reasons. Only six of the thirteen groups who received a placemat instruction for the silly walks challenge and five of the twelve groups who received a placemat for the tug-of-war challenge referenced the placemats in a way that sparked some kind of conversation between partners or incorporated one of the ideas on the placemat instruction into their robot build or code.

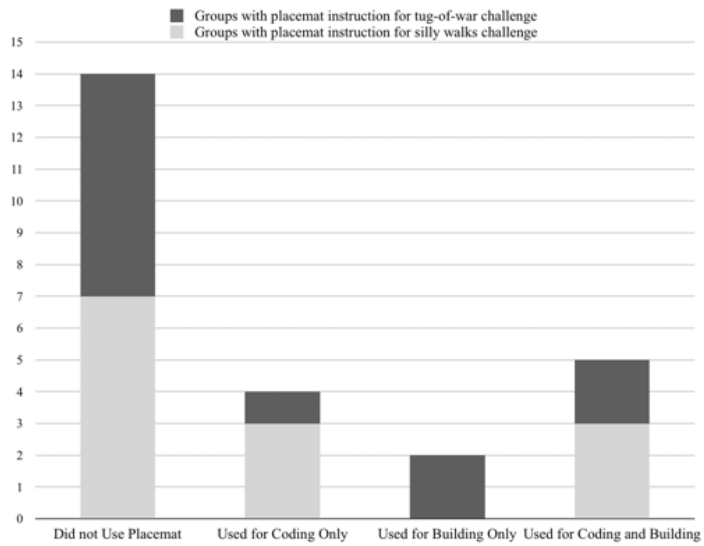

Fig. 3. Usage summary of placemat instructions among the twenty-five students pairs in the study population

The majority of the groups who referenced the placemat instructions did so for help with coding. Many students were unfamiliar with the LEGO MINDSTORMS Education block-based software. As the students began trying to code their robot many of them raised their hand to ask for help finding the correct blocks to use. This happened in all four of classes during the silly walks activity, as it was the first time students were opening up the software in several weeks. In both of the sections where the placemat instructions were used for silly walks, the teachers used the placemat instructions as a way to point out which blocks to use to the whole class.

There was a large diversity of solutions to both challenges across all of the sections. There were only four total instances out of twenty-five total groups (three in the silly walks challenge and one in the tug-of-war challenge) where students built the exact model shown on the placemat. This was encouraging to see, as it illustrates that the presence of the placemat did not perpetuate the idea that there was one correct answer.

We also analyzed the time it took students to complete a first testable prototype with and without the placemat instruction. Across the eleven groups that used the placemat instructions, there was no trend in the time it took students to reach a first testable prototype compared to when they did not have access to a placemat instruction. There was also no trend in how quickly students who chose to use the placemat instructions reached a testable prototype compared to their peers who chose not to use the placemat instruction. This validates the idea that placemats are a support for students who feel they need them, but not a tool that needs to be leveraged by every student. In a select case documented below, the placemat instruction was key in helping a group get started on building their first prototype, which in turn enabled them to have enough time to test and iterate. The sooner students were able to complete the first prototype, the more testing and iteration they were able to engage in, which is a valuable part of the engineering design process.

4.2 Specific Use Cases

There were three cases in particular that exemplified situations where the placemat instruction was particularly helpful for both the students and the teacher. These three instances are described below.

The case of "We don't have any ideas." Anna and Matt (pseudonyms) spent the first minute of their silly walks challenge silently staring at the placemat instruction in front of them. The conversation below followed:

> *Matt*: Do you, um, have any ideas of what we should make?
> *Anna*: Uh…no. Do you?
> *Matt*: Not really, I … no I don't have any I don't think
> *Anna*: [opens LEGO MINDSTORMS Education EV3 kit and picks up a few of the pieces without saying anything] Should we make it walk or something?
> *Matt*: Yeah OK. How would we do that.
> *Anna*: We could make it like this [points to back of placemat instruction where there is an exploded view of the scooting walker robot]

These two students seemed to have trouble coming up with initial ideas and on their own were hesitant to start experimenting. They then leverage the placemat instruction by using one of the provided ideas to get started. They both worked together to build the scooting robot and then modified the code multiple times to get it to move forward by moving one leg at a time instead of two as depicted in the placemat example code.

During the next class period, Anna and Matt were then presented with the tug-of-war challenge. A similar conversation occurred, with neither of them offering up an idea or starting to build. After approximately three minutes the teacher went over and helped Matt and Anna brainstorm ways of attaching the motors to the EV3 brick to create a driving base. While Anna and Matt still had time to build a functional tug-of-war robot and test it against two different opponents, it took them almost twice as long to get started and required their teacher to notice them struggling and appropriately intervene. This is just one case where students benefitted from having the placemats available to help them get started.

The case of "We want to build it this way." Kevin and Eric (pseudonyms) were very excited about the silly walks challenge and immediately decided that they were going to build a robot that had legs and could walk. However, after twenty minutes of building they still hadn't succeeded in building anything close to a robot that could walk. They began to get frustrated and lose interest and started making silly faces into the camera. The teacher noticed and went over to ask them about their design. They told her that they wanted to make a robot that could walk but didn't know how. The teacher then flipped the placemat over and showed them the scooting walker. "This one kind of has legs, why don't you give that a try?" she prompted. Kevin and Eric got back on task and were able to finish their silly walker in time to test it out with two different leg configurations.

In the tug-of-war challenge, where Kevin and Eric did not have a placemat, they initially had the idea of making a braking system. Their idea was to add brakes to their car so that if it started getting pulled by the opposing car the brakes would activate and stop the car from moving forward. After tinkering with the pieces for a few minutes, Kevin and Eric decided that they didn't know how to build brakes, so instead they would use the USB cord included in their robotics kit to tie their robot to the leg of the table and use that as a mechanism for keeping their robot from being pulled over the line. This caused some disruption in the classroom and other students viewed using the USB cord as cheating. The teacher then had to speak with Kevin and Eric multiple times about coming up with other ideas in an effort to prevent them from becoming off task and disruptive to the rest of the students.

In this case, the placemat instruction was a helpful tool for students who had a very set idea of what they wanted to build but weren't sure how to achieve it. While the placemat instruction for the tug-of-war challenge did not offer any ideas for how to build a brake system, it did offer other ideas that may have inspired Kevin and Eric to stay more on topic, just as the silly walks placemat instruction was able facilitate them getting back on track with building their walking robot.

The case of "What if we do it wrong?" Alexa and Samantha (pseudonyms) struggled initially with the silly walks challenge. They did not have a placemat for this challenge and Alexa in particular was having a hard time picking an idea or even just trying something out. Samantha asked her if she had any ideas and she responded that she didn't really have any. Samantha started pulling pieces out of the LEGO MINDSTORMS Education EV3 kit and started to build, explaining to Alexa that she thought they could build a robot that used a rotating beam to move forward instead of a wheel. Samantha continued building the robot and Alexa remained un-engaged. The teacher later explained to us that Alexa struggled significantly with anxiety and often was unable to attempt problems that didn't have a defined correct answer. Her fear of being wrong prevented her from engaging in the activity altogether for most of the challenge. Only towards the end did she help Samantha try out a few different beam configurations after she saw that the robot did in fact move forward successfully.

When it was time for the tug-of-war challenge, Alexa and Samantha looked at the placemat together. Having the opportunity to see some different examples gave Alexa an entry point into engaging in the activity. Samantha told Alexa that she wanted their car to have four wheels and Alexa confirmed that she was okay with that. Samantha began attaching the motors to the EV3 brick. Alexa looked at the placemat some more and then started getting out the pieces needed to add the caster wheel onto the EV3 Brick as depicted in the placemat instruction (Fig. 2, top left of back page). Samantha and Alexa collaboratively built a three-wheeled car and tested it against two components. Having the placemat seemed to give Alexa a feeling of security and a sense that she was "doing it right", despite there being no "right" answer to the tug-of-war challenge. For students like Alexa who are afraid to fail, having a scaffold that helps them feel as though they are on the right track throughout the problem-solving process is helpful. The placemat instruction served this purpose here, enabling Alexa to be an active participant in the activity without needing constant teacher encouragement and support.

4 Conclusions

Based on the case study presented in this paper, the placemat instructions were successful in: (1) helping students to quickly and easily get started with an open-ended design challenge, (2) supporting students and teachers when issues or questions arose during the activity, and (3) inspiring a diverse set of solutions to single challenge. While the placemat instructions were only used by a minority of the groups in this study, they did have a clear positive impact on some of the use cases described above. The idea of students self-selecting the level of support they extracted from the placemat instruction proved effective and the learning experiences that unfolded in the classroom were positive. In the case of this study population, the placemat instructions did not limit the diversity of student solutions to a design problem, and in specific cases were instrumental in helping students get started, stay on task, alleviate frustration, or engage meaningfully with the challenge. In an ideal classroom, free from many of the challenges typically found in open-ended robotics challenges, placemat instructions would not be needed. The fact that we saw so few students leveraging them is an aligned with the fact that this study population was not dealing with many of the traditional problems that placemat instructions help to alleviate (such as high student to teacher ratios and teachers that are unfamiliar with the technology).

In future studies, we hope to investigate the use of placemat instructions with younger students and with a more diverse study population. We also hope to conduct research on how the teachers' experiences change when they are able to use a placemat to support an engineering design challenge. In this study, we saw preliminary indicators that the placemat instruction supported not only the students, but also the teacher. This discovery does not come from thorough research but rather from this one case study and therefore can only suggest potential directions for a more comprehensive study. In the future, we hope to explore this idea further to find out how to optimize the design of the placemat instructions to best support positive learning processes and outcomes for students and educators alike. We also plan to continue to iterate on the format and structure of the placemat instructions and conduct studies to analyze how variations in the placemat design effect usage outcomes.

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