Coordinate: MARS

Presented to Professor Jan L. Plass

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Game Rules

1) Players advance through the levels of this single-player game by solving the puzzle missions. This is done by inputting the correct numerical data into the question spaces, via keyboard and mouse.
2) The game is won when all the levels have been successfully completed.

1. Introduction

Coordinate: MARS is a single-player computer game designed to teach younger middle-school-aged children fundamental concepts relating to the Cartesian coordinate system and 3D mapping, via a series of humorous puzzle-like challenges. The game offers players a hands-on introduction to concepts such as the XYZ axes, fixed origin coordinates, relational coordinates, and basic spatial algebra.

The game is built as a series of levels, in which players are thrust into the shoes of various professionals working on a space colony mission (spaceship dispatcher, urban planner, etc.), and confronted with spatial mapping challenges. Players advance through the levels via inputting coordinate data. The game is won by successfully establishing a sustainable colony on the planet Mars.

The game is designed as a familiarizing tool: by providing students with the ideas and uses of coordinate mapping in three-dimensional space, it aims to supply them with a solid basis with which to delve into the more hard-core mechanics of the concept.

The importance of this subject matter to young students can hardly be overestimated: The Cartesian coordinate system forms the basis of modern geometry and serves as the foundation for physics, engineering, astronomy, and so forth. While of cardinal importance to STEM education in general, the ability to understand and articulate space via maps is deeply tied to countless other walks of life, from spelunking to computer-aided design, from navigating museums to navigating seas.

Thus, we consider it a useful approach to introduce this educational material via such real-life examples - presented in an interactive game interface - rather than following the traditional method of solving abstract problems from a book. We believe this game might lend itself to curricular incorporation, as a way to welcome and expose students to the world of 3D geometry and help them approach and understand more complex formula-based concepts at later stages.

2. Background

Target Audience

Coordinate: MARS has been designed primarily for middle school students.
The game situates the content learning within challenges derived from ‘real-world’ problems derived from professions that typically evoke interest among children of this age, and thus demonstrates the relevance and application of the subject matter at hand in a targeted way.

The game's sci-fi narrative reflects themes common in popular culture. It will include the option to play in different languages, and thus cater to international audiences or to language minority students.

For a learner, the game will take about 30 - 45 minutes to complete, thus lending itself to curricular integration as a special homework session. The learners needn't have any prior knowledge of 3D axes system, but a basic exposure to the 2D graph system will be helpful as it will increase the speed of players.

Educational/Learning Objectives

Upon completion of this game, students will be able to (a) better understand concepts relating to 3D space, as well as engage in analytic thinking that applies to the application of this knowledge, and (b) relate the learned concepts to real-world scenarios where this knowledge can be applied.

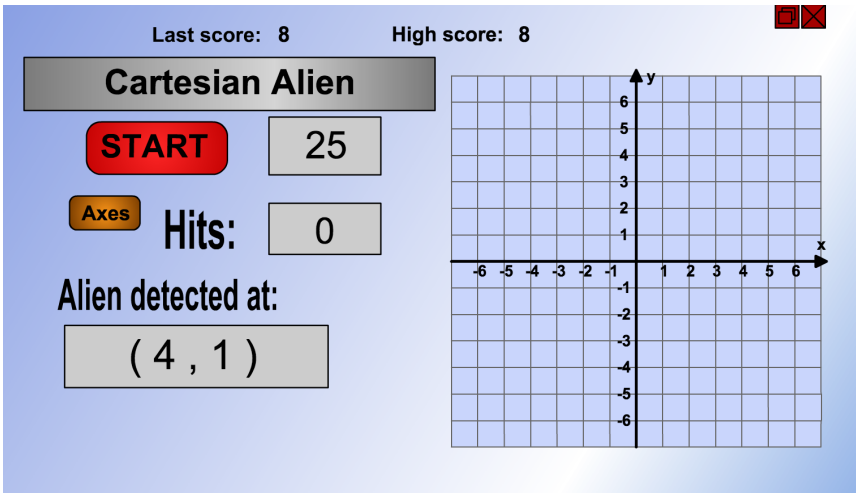
According to the Bloom's Taxonomy (Bloom et al., 1965), the following dimensions will be implemented in design of the game: *Knowledge, comprehension, application, and analysis*. By the end of the game, students will have a strong conceptual understanding of 3D axes and coordinate mapping which can be used as building blocks for further complex concepts such as equation of line, slope of line, etc.

Description of Content

It is assumed that learners will have some prior knowledge of working with two axes, hence the game's initial levels contain 2D axes challenges before progressing to all three. The game is designed as an introductory tool for formal classrooms to familiarize students with the content in an engaging, interactive way and also help them transfer this knowledge to real life by exposing them to application-based situations. Hence, it does not introduce formulas or complex equations, in order to avoid a steep cognitive load for learners taking their first steps. A more rigorous encounter with the material may be built upon the foundational base established by the game design.

Market Analysis

As per our research, several apps and games (digital and board) are available to teach 2D coordinate geometry. Games such as Study ladder and Cartesian Alien, may provide some value for students, yet are very limited in their scope and engagement. The following is a screenshot to demonstrate the interface of the latter game, in which users are asked to use their mouse to point at the grid-coordinate that corresponds with the data of where the alien was detected. This limited narrative and surface-level connection of the learning mechanic to the game mechanic is typical of our findings. As far as 3D grids are concerned, we could not find any games that attempt to tackle the task. One example of an attempt to involve playfulness in the task is Treasure Finding, which offers a playful, puzzle-like way to practice the concepts involved.



3. Design

General Design

Coordinate: MARS is a single-player game played online via a browser, on any type of personal computer. It requires the player to be familiar with a keyboard and mouse/trackpad. There aren't any explicit rules of play. The narrative itself will unfold the directions of play for the players.

The game is designed as a series of increasingly complex levels through which the player advances. In each level, the player is placed in the role of a different character on a mission-to-Mars team. The first levels take place on Earth in preparation of the launch, and later ones happen on Mars. In order to beat the levels, the player must calculate and input correct data, according to the challenges presented by the characters.

The game contains two types of levels: Regular missions and ‘clock missions.’ The regular missions form the backbone of the game: It is through these that the general game mechanic is understood, the mathematical concepts are introduced, and the narrative is advanced. The game is won when all the regular missions have been completed. Clock missions, which play a more specific role, occur intermittently, and will be explained separately.

Level progression

Early in the game, the regular missions have the player locate a single coordinate on two axes (flat ground), using only positive values and an absolute origin point. For example, (Fig. 1) the player (who always appears on the right) was asked to provide a specific coordinate (the orange warehouse) to a CG character (the truck driver), and has entered the number 9 into both fields.

Fig. 1

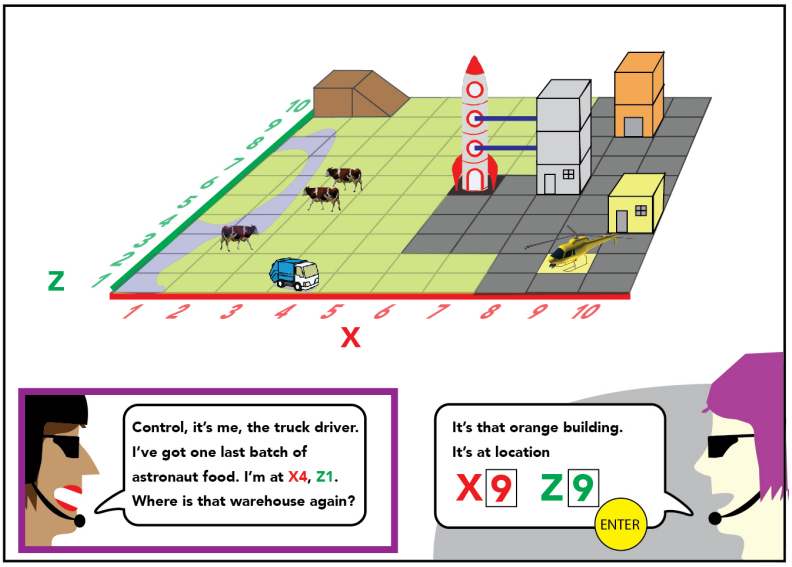
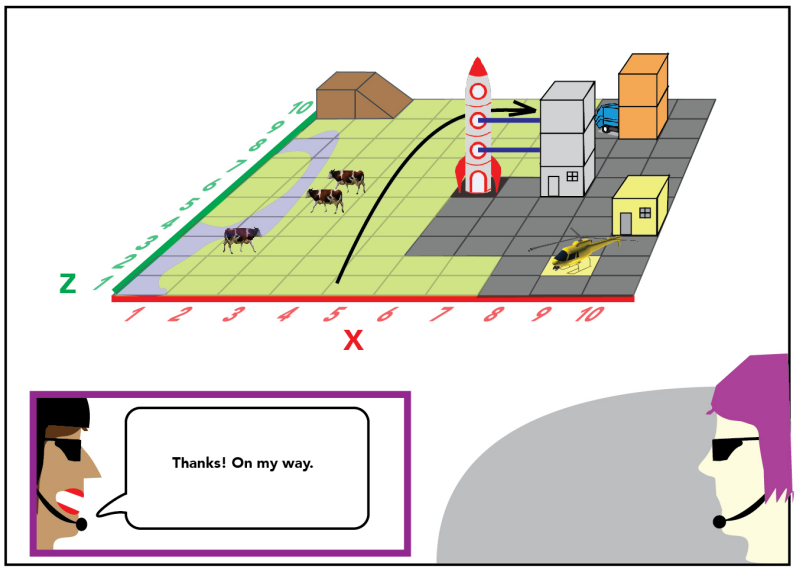


Fig. 2



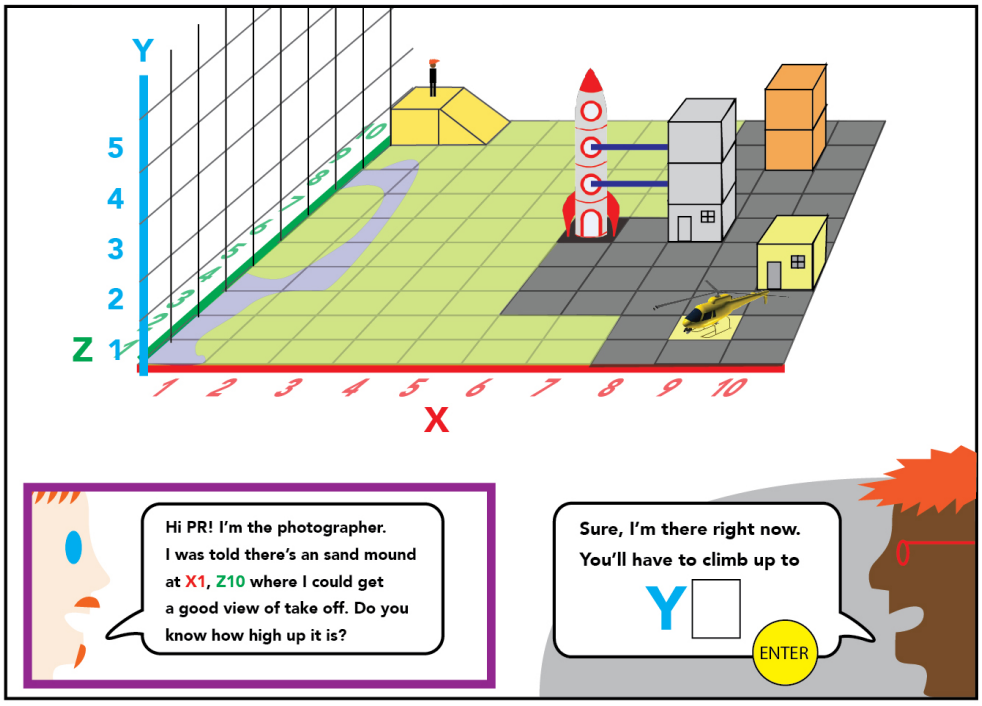
The player then submits the data, and if it was correct, a short animation demonstrates the implementation of this data (the truck is driven into the warehouse, see Fig. 2), and the player advances to the next mission - which may be on the same terrain map, or may be on a new one. (In this early stage of the game, it should be noted, the player is asked to input only one coordinate, hence the animated sequence - in this case, the truck's route - is predetermined.)

Problems involving vertical axis Y are introduced at a later stage, once the player has demonstrated an understanding of the game mechanic and the interface.

Fig. 3 illustrates an early occurrence of a problem involving the Y axis. In it, the player is asked to calculate only a Y axis value. In this terrain-based layout, the task of calculating values in relation to vertical axis Y is significantly less intuitive than that of dealing with X and Z 'ground' axes, and poses a much higher intrinsic load. Our solution

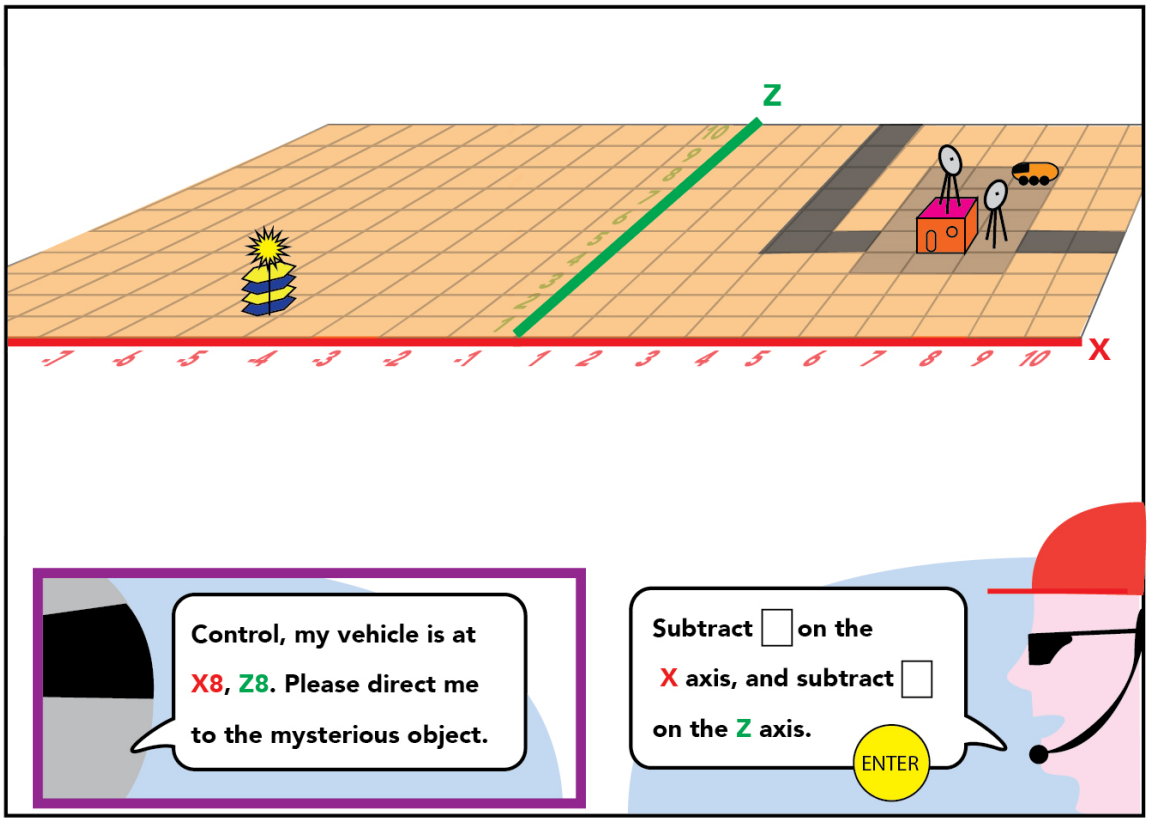
is to use a shorter Y axis, and to allow players the ability to toggle on and off the Y axis gridlines.

Fig. 3



Once players demonstrate competency with the Y axis, problems are introduced which entail dealing with additional mathematical complexities: (a) Rather than being asked to locate one particular coordinate, players must calculate routes between two coordinates; (b) negative numbers are incorporated; and (c) the user must input values based on relations which do not refer to an absolute origin. The Mars-level mission illustrated in Fig. 4 demonstrates these three points:

Fig. 4



The following table summarizes the content matter progression, from early to advanced missions, with the left column listing the four central mathematical factors.

	Early missions	***Advanced missions***
Number of axes	Two	Three
Coordinate input	Point-based	Relation-based
Values	Positive only	Positive and negative
Absolute origin point	Referenced	Not referenced

The following two tables list examples of challenges. The narrative problem is listed on the left, and the types of mathematical challenges it incorporates are listed on the right. Pre-launch Earth missions are in the green table, and Mars missions follow in orange.

Earth	
Help helicopter pilot collect technician from opposite side of river	*2 axes, point based, absolute origin*
Help veterinarian find all the cows to move them away from the launch site	*2 axes, point based, absolute origin*
Help technicians find tallest spot on map to install interplanetary beacon	*3 axes, point based, absolute origin*

Mars	
Locate best place to land ship	*3 axes, point based, absolute origin*
Locate best place to set up habitat, farm based on ship's location	*3 axes, point based, relative origin*
Plan road from spaceship to habitat, farm	*3 axes, connection based, relative origin*

Narrative design and clock missions

Success may prove elusive or difficult, but there is no lose state in *Coordinate: MARS*. The intrinsic incentive system is based on building an interest in the narrative, rather than on fear of failure or on a sense of competition. That said, in order to add a measure of excitement to the gameplay, occasionally players will encounter a clock mission. These missions must be completed within a given amount of time, and thus present players with a short-term goal which has a lose state. Failure to beat these missions will *not* lead to a setback in the gameplay - rather, only to a momentary, contained defeat, framed in a humorous way.

For example:

Mission: Spaceship's cook forgot to bring salt. Aid her in last-minute delivery effort. **Take-off imminent**	***Win state:*** *Crew members happy* ***Lose state:*** *Spaceship takes off sans salt*

If the player fails to beat the clock, they will be allowed to try again until they succeed. The mission narrative moves forward regardless of the outcome of the clock missions. Success or failure to overcome these challenges impacts the narrative only as a joke: In addition to the 'result,' players will be humorously reminded of their specific defeats/victories later on in the game. For example, upon completing the following

regular mission, players will be reminded of their earlier success or failure in the clock mission described above:

Mission: 1-year on Mars party planned. Help driver deliver extra load of produce from farm	***If earlier 'salt mission' was accomplished:*** *Crew throws feast, rejoices with great salty food*	***If earlier 'salt mission' was abandoned:*** *Crew throws feast, bitterly complains about tasteless food*

The macro-narrative's plot points are fixed, but the clock missions allow the user to enjoy a self-conscious flexibility in the form of shaping nested micro-narratives. The user's pleasure here, to borrow from Jenkins (2004), is to be found in the experiences along the road.

Visual design

As the draft wireframes hopefully suggest, the game's visual design will strive to strike a balance between a schematic, minimalistic style and an emotionally appealing one. The importance of avoiding a situation of cognitive overload caused by superfluous data in learning games is well documented (Plass, Homer, Hayward, 2009), as are the benefits for learners in generating a sustained emotional interest and enjoyment of the content matter (Plass & Kaplan, 2014). In order to avoid cognitive overload, elements that are

superfluous to the puzzles and/or plot will be kept to a minimum, and included only if deemed valuable to increasing the game's intrinsic interest. For instance, Mars' surface will be rendered a reddish hue - but will not be granted texture or any additional non-plot-related details (craters, fissures, etc). Individual coordinate-grid elements such as vehicles and buildings will be granted some embellishment, but this clemency will not be afforded to the empty spaces in between them, as it is the calculation of these spaces that form the heart of the cognitive challenges.

Additionally, there is no need to remain stylistically sparse when rendering the team members. The characters exist, in a sense, *outside* of the representational problem space, pointing to it - and thus they are less likely to pose a distraction. An appealing design may add to the players' emotional connection to the narrative at hand, and thus would be beneficial.

This approach holds true to the animations as well, which will be expressively animated. The animated sequences form an important part of the learning mechanic - they are a central part of the all-important (Salen & Zimmerman, 2003) action-outcome feedback mechanism that conveys to the player the result of his/her calculations. Yet they do this *after* the player has offered their solution, and thus, the animations are well-suited to serve as a moment of enjoyable respite between the missions, and an additional incentive in themselves.

4. Theory

Theory of Change (Logic Model)

The logic model which forms the basis of the game takes into account elements from both the constructivist and behaviorist streams. Constructivist in the sense that players actively expand their knowledge by meaningfully engaging in open-ended narrative presented at different levels. Students are encouraged to explore the world and see what happens when they ‘misbehave’ and input ‘wrong’ coordinates. The feedback mechanism serves as a medium to guide learners onto the right track so as to move ahead in the game levels. The use of the different roles the player assumes has its underpinnings in the theory of transferability of learning. Through this mechanism, the design encourages players to think about the practical applications of the three-dimensional coordinate mapping. The core mechanic itself, of problems to be solved in one particular manner, is on the behaviorist side of the spectrum, and at heart it is not fundamentally divorced from the mathematical testing realities most students face.
The following will the model that can be used to represent the underlying the conceptual framework for this game. It delineates the learner objectives, the tasks that can help accomplish the aim as well as the evidence that will classify whether the learning objective was achieved or no. It also links to the mechanics that will be used to present those mechanics for accomplishing the required tasks.

Evidence-Centered Design Model

Learner Models	Evidence Models	Task Models	Presentation Models
Whats should be learned?	What behaviors teach these constructs?	What tasks and activities elicit these behaviors?	How should these tasks be presented? (mechanics)
Teach concept of x,y,z axes	Identify the correct location of the object	Enter the accurate position values for the objects	Player has to enter the numerical values in the box to define the accurate location
Map the coordinate on x,y,z axes	Give the correct coordinates for tracing the location of object	Report the coordinates to the helicopter pilot according to mission assigned	Player has to enter the values in the box which is used for communication to the helicopter pilot so that mission can be completed

Cognitive Design

As such, *Coordinate: MARS* incorporates in an interactive, dynamic way educational objectives and content, learner characteristics, and prior knowledge that may help in the integration of this game into a formal education curriculum. It is a well-established fact that the educational efficacy of visualizations depends on the synchronicity of the design with the human cognitive architecture (Mayer, 2005a). The game's visual interface is designed according to the cognitive load theory of multimedia learning (Mayer, 1947), which states that textual and graphical elements must be devised in a balanced form in order to avoid extraneous overload and allow for generative cognitive processing. Starting the game with only 2 axes activates students' prior knowledge, thus facilitating the integration of new learning material into pre-existing schemata.

Affective Design

Coordinate: MARS is heavily based on evoking a high level of intrinsic interest, and general affective considerations have been taken into account in order to allow for its players to engage in meaningful learning (Isbister, Flanagan, Hash, 2010) facilitated by enjoyment. The player is encouraged to feel responsible for the advancement and happiness of the crewmembers, to take pleasure in their successes, and to have an occasional laugh at their expense. In addition to the visual approaches outlined earlier, a dramatic soundtrack and effects will be utilized to increase the situational interest. Humor will be widely used in the narrative as well as the graphic and motion design to arouse the players' interest and enjoyment. Lastly, the unexpected clock missions will add an activating emotional element.

Social Design

While a multiplayer competitive/collaborative mode might help further involve some students, at this point we are satisfied with the single-player design, which more closely mirrors the evaluation systems typically found in schools.

While completion of the game strongly implies a solid grasp of the concepts, the clock-missions could be used as a method of evaluating students' efforts and ability to solve the problems under a time constraint: all one would need is to add a 'crew happiness meter,' the levels of which would recedes if the clock missions are abandoned rather than overcome. A teacher could then request students to win the game with at least

75% happiness, etc. But for this iteration, we will aim to uphold the approach well outlined by Jim Gee (2009) - beating the game implies no need for further evaluation.

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