Managing the Tradeoffs in the Digital Transformation of an Educational Board Game to a Computer-based Simulation

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Abstract

There is a need for new pedagogical strategies to educate the current generation of engineering students who are still typically taught using standard lecture practices. The desire to address complex technological and social issues in an engaged manner inspired the development of a prototype board game created to raise the awareness of environmental issues in engineering. The board game, Shortfall, was designed as part of a graduate thesis for in-class play by undergraduate and graduate engineering students as well as business students. The game structure was based on team competition of "companies" in the automobile supply chain, with the game objective set to achieve the highest profit. In 2005, it was evident that developments in digital technology allowed new opportunities to engage students in collaborative and active learning. A team of engineers, educators and designers further developed the board game with more in-depth scenarios and graphic organization. The game was then play tested and assessed learning and game play as an initial step in the process of developing a multi-player computer-based version of Shortfall.

Student feedback from play testing, focus groups and surveys provided insights for redesigning the game for the computer platform. Two senior undergraduate engineering students in an independent study took these results and have created a prototype computer-based simulation designed as an experimental educational technology for an engineering course on environmentally benign manufacturing. This prototype was created to be the first computer-based step towards a fully networked multiplayer implementation. The transformation from board game to computer-based simulation presented many new challenges and tradeoffs, which are detailed in this paper. The goal was to maintain the core mechanics of the board game so that intellectual merit was not lost in translation while forging the first computer-based implementation.

Keywords: educational technology, serious games, supply chain simulation, environmentally benign manufacturing

CCS: K.3.1 [Computers and Education]: Computer Uses in Education – Collaborative Learning

1 Introduction

Solutions to environmental problems associated with human endeavors are generally interconnected with many factors, including technological and economic constraints – often requiring a systems engineering approach. To create a culture for change in industry, students must begin to understand how to assess the tradeoffs among economic, technical and environmental factors if they are to become socially, as well as fiscally, responsible designers and leaders. Because of their unique learning style and technology expertise, the "Millennial Generation" brings significant learning and teaching challenges to the classroom. In an effort to accommodate the learning styles of this generation, a new pedagogical scheme built on collaboration, active learning and discovery offers alternative methods for teaching and learning [Howe and Strauss 2000, Brown 2000]. There is the need for an educational tool that presents an opportunity to bring the growing concerns of environmental awareness and diverse learning styles together in an innovative learning model to educate future engineering leaders.

One alternative educational method is the creation of an active simulation that encompasses the economic, technological and environmental factors of an engineering system. The system we chose to adapt was based on a board game, Shortfall, which simulates the automobile supply chain [Corriere 2002]. The mechanics behind the original board game were designed to present and assess knowledge in several areas, with objectives to improve not only overall knowledge in these areas, but also confidence and decision making abilities based on this knowledge. The key knowledge areas for the original game included:

- History of environmentally benign technologies within the past decade
- Environmental policies and legislation that influence manufacturing in the global economy
- Current business strategies and technologies used in industry to address environmental burdens
- Trade-offs among economic and environmental factors that influence technology
- Effects of current global events on sophisticated supply chain and complex engineering system
- Team-based decision-making in management of a complex set of variables for expected outcome

A multidisciplinary team of faculty, staff and students from several different departments at Northeastern University (NU) worked to adapt and redesign the prototype board game from its original incarnation. The Department of Mechanical and Industrial Engineering provided the technical background; the Department of Visual Arts and Multimedia Studies provided the interactive and graphic design expertise; and the Center for Effective University Teaching provided the critical learning assessment skills. Metaversal Studios, a game development company that specializes in educational games was added to the team. The diverse team was established to create a revised board game as an initial step in the process of developing a networked multi-player computer-based version of Shortfall. The revised board game was intended to create a fun learning experience for students, but also to utilize a collaborative learning environment such that engineering students would learn and retain the key knowledge concepts.

The most recent work on this project has been undertaken as an independent study course for a pair of senior undergraduate engineering students. The students transitioned the Shortfall board game into a basic computer-based prototype. By harnessing the knowledge from the board game and building upon many of the original concepts, the two students redesigned the game experience. It became clear that many of limitations of the board game could be solved through a computer-based implementation, but this change raised many interesting new challenges. This paper chronicles the work done to minimize these tradeoffs in bringing Shortfall to the next stage of development.

2 Shortfall: The Board Game

The original board game version of Shortfall was designed as part of an engineering M.S. thesis [Corriere 2002] that was supported by the National Science Foundation (NSF) (DMI-9734054) and the NSF funded NU Connections Program (HRD-9813896). The board game modeled the supply chain of an automobile manufacturing operation. The original game was played several times with engineering students and once with business students. The goal of the game was to teach students to minimize environmental impacts while maximizing profits, and to create dialogue about this balance. An early prototype of the original board game was formally assessed, and students indicated that they enjoyed playing it and that the game was informative.

A second enhanced board game version of Shortfall was designed with the knowledge of the successes and limitations of the first prototype. Metaversal Studios was consulted to enhance the overall game play experience, with a focus on graphic organization, fully developed scenarios, and game play logistics. The revised second version of Shortfall was piloted in the Fall semester of 2005. The game offered students opportunities to assess many weighted decisions to indicate that business decisions that include environmental factors are not "cut and dry".

The game allowed for competition among three teams or companies in the automobile supply chain: materials (Tier 2 suppliers), parts (Tier 1 suppliers), and cars (original equipment manufacturers, or OEMs). Each team or company consisted of four roles: the Chief Executive Officer (CEO), the Environmental Manager, the Research and Development (R&D) Manager, and the Production Manager. The roles of each team member in the company during play differed. The CEO made the final budget allocation decisions for each quarter. The Environmental Managers of each team were charged with the tasks of waste disposal, recovery, and recycling. The R&D Managers spent their allocated funds on technological improvements in the form of Innovation cards that were played depending on the budget of the CEO. If the CEO chose to budget enough money to the R&D Manager, then the R&D Manager could impose multiple upgrades each turn. The Production Manager used the allotted budget each turn to create product (materials or parts or cars) and purchase goods (raw materials, materials or parts). The teams needed to interact and work together in order to make their companies successful. However, the teams were also in competition with each other to create the most green and profitable businesses. This combination of game mechanics, both cooperation and competition, created a scenario that promoted interaction among the students and immersed them in the business world with real life tradeoffs involving new technologies, new environmentally benign manufacturing processes and business economics.

The game was played in rounds; each round represented a fiscal quarter. The last round or quarter played was a "sell off" round where the teams sold off the assets of their companies and also paid to dispose of any remaining waste. The most profitable company (team) was deemed the winner in the board game. The concept of green score was not implemented at this time, and hence student teams competed only on the basis of profitability, although work on addressing less arbitrary values for green scores continued [Torabkhani et al 2007].

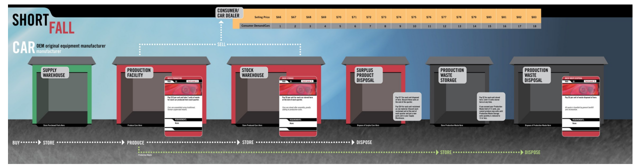

Figure 1 - Shortfall Automobile Manufacturer Team Board

Twelve sophomores self selected to play test the enhanced version of the Shortfall board game. The first round lasted for 30 minutes while the students adjusted to the rules and flow of the game. The subsequent rounds took between 5 and 20 minutes each. The game consisted of 5 rounds, 4 rounds of normal play and 1 final round for the teams to "sell off". At the beginning of each quarter the teams created their budgets privately. The teams also planned their production carefully, because they could only sell completed product. Therefore, each team had to plan at least one quarter in advance to maximize their profits. The production of new product was limited by: the company's budget, the number of parts/materials that the company had available, the amount of waste and product storage that the company had, and the random market fluctuations that were integrated into the game. Companies were charged a fee for waste disposal; however costs could be reduced for environmentally benign disposal or recycling. At the end of each round/quarter, all product, materials, and waste were assessed a storage fee and a Current Event card was played. The Current Event cards depicted real world environmental situations that impacted different areas of the supply chain from landfill seepage to pollution regulation. In the last round, the 5th quarter, companies did not produce additional product, but instead were allowed to sell off all assets to the open market. Each team also had to spend funds to dispose of all waste. After this final round, the company with the highest profit had won the game. Further details of rules and game play are presented elsewhere [Isaacs et al 2006].

2.1 Analysis of the Board Game

A program survey that identified the strengths and weaknesses of Shortfall as a board game was administered to each of the twelve students. One week after playing the game, the students were also invited to a focus group exploring their experiences with the game and their perceived feelings about Shortfall as a learning tool. An assessment of the knowledge gained during and after game play seemed to indicate that student learning occurred through game play [Qualters et al, 2006]. Most of the student suggestions centered on 1) the overall game balance, 2) the structure of innovation cards (or the innovation system), and 3) game mechanics and logistics.

Issues with the overall game balance laid in three areas: balance among the companies in the supply chain, balance within the companies themselves (player roles), and the Current Event cards. The simplified supply chain consisted of only three companies: Materials, Parts, and Cars (OEM). The materials company obtained their raw materials from the open market while the OEM sold their product to the open market. This created a bottleneck for the parts company, because it exists in the middle of the supply chain and was therefore at the mercy of the other two teams. Regarding the player roles (or balance within each company), some students felt that there was overlap between some roles, while others felt their role as Environmental or R&D Manager left them with little to do. The CEO role seemed to dominate the team and created the most active decision maker. The Current Event cards were uniformly agreed to be clear and concise with little change needed, but more variety was suggested with the caveat that the cards should equally impact companies in the supply chain.

The issues associated with the structure of the Innovation Cards, or the "Innovation System" included: no clear progression of cards in the technology tree, limited choices of technology, limited real world information, and not enough information on other teams' technology options. Further, it appeared that many of the innovation choices that were selected by student teams during game play were based purely on business economics rather than deliberation of the environmental tradeoffs. There was no balancing of the Innovation Cards, and the students were not given a "bigger picture" of what the Innovation Cards could do for each company. Most of the information presented to the students about environmentally benign manufacturing was introduced through the Innovation Cards, but many students overlooked the text facts provided on the cards, skipping to read only the cost values associated with the card. When asked about this during the focus group, students suggested that the cards either needed to be rewritten or contain more information. In the board game, the only true win condition is the company with the most profit. There were no means to include changes in market for customer preferences or company image. Hence teams tended to make their decisions based on the bottom line (profit) instead of considering customer preferences or a resulting company image.

The game logistics and mechanics of the Shortfall board game also had issues, including: length of rounds, number of rounds, lack of a clear concise manual, cumbersome game materials, lack of easy scoring methods, and the need for manual calculation. The length of the rounds varied from 5-30 minutes and this was too long for many players. Because the rounds were so long, the number of rounds had to be reduced (to create a reasonable game duration), and players found that there were not enough rounds to really get a feel for the game play or rules. The board game required three separate boards and several different markers to depict the materials and product flows that each company bought, produced, and sold. The necessity of these game props led to much confusion in the rules (even with the rules read by a facilitator at the beginning of the game). Finally, to work with the budgets for the production and management of products and waste, each team needed to perform calculations on a calculator using a set of worksheets. Students felt that this detracted from the overall experience of the game.

The strongest theme resulting from the focus group was student perceptions that the game helped them more with the teamwork/communication aspects of supply chain than engineering or technical concepts. This led students to suggest that another improvement would be to make the game more realistic and more complex. A suggestion was made to create several automobile manufacturing company teams that compete for goods from the same supply chain, instead of having teams competing as companies within the chain.

As a learning method, students almost unanimously felt that the game should function as a "lab", that is, most students felt they needed an introductory lecture first, and then playing the game would solidify the concepts. There was also feedback that the instructions were not clear enough; a rule and reference manual would be helpful. This lack of ability to find needed information quickly during the course of the game may have accounted for the students feeling that a content framework is needed first to successfully play the game. When asked to think about the process they went through to make strategic decisions during the game, students again identified that the initial rounds were devoted to "learning the game" and only after they understood how to play could they begin to play strategically. It also appeared that the strategic aspect depended on how the CEO in each team functioned: some appeared to be more democratic while others more authoritarian.

3 Shortfall Computer-based Simulation

By assessing the comments from the student focus group and the program survey, it became clear that certain areas needed to be redesigned. Although students generally enjoyed the game play, and had retained knowledge after game play, the issues identified regarding overall game balance, the Innovation System (the technology tree), as well as game mechanics and logistics remained obstacles for effective learning. A redesign to transition the board game to a computer-based simulation would allow these issues to be addressed, and an initial prototype was created.

Fundamental changes were made to the game design, resulting in completely restructured game play, scoring and strategy. With the ability to do rapid computation on the computer, the game could now be expanded to include ten (10) rounds. This would allow for more flexibility in design, because players would be able to consider both long term and short term goals while evaluating environmental engineering changes. A "green score" was also introduced in order to give an environmental goal along with an economic goal. The team structure was reoriented so that there was no longer competition within the supply chain; instead the focus changed to a supply chain vs. supply chain competition, i.e., each student team would consist of six players, who would represent three companies in a supply chain (materials, part and cars (OEM)). Although this structure does not represent the reality of business, it allows development of a prototype to test the game in the new platform. All of the adaptations based on student feedback suggested the necessity of the platform switch – a transformation from board game to computer game.

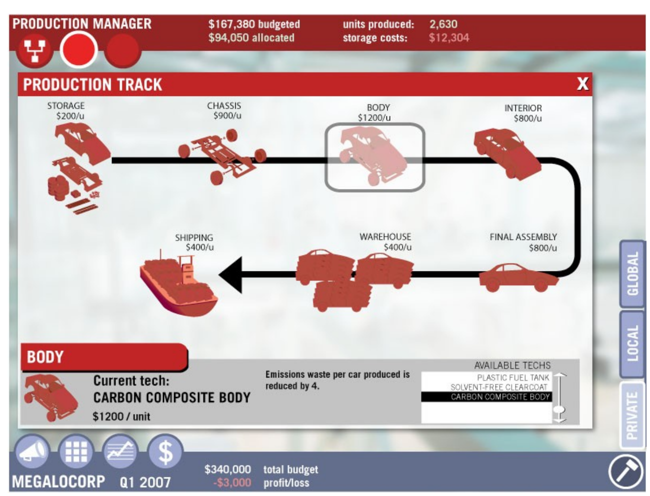

Figure 2 - Prototype Screenshot Mockup

3.1 Overall Game Balance

Many students identified key problems with the balance of the game. These problems included the balance within the supply chain, on the OEM Tier and in the Current Event cards. It was extremely important to make the game feel as balanced as possible so that fairness and luck were not taking away from the educational aspects of the game.

To combat the issue of balance within the supply chain, the game was restructured to have each team play and compete as an independent supply chain rather than competing as independent materials, parts and cars (OEM) companies. In a future version, this oversimplification will be addressed. But as a starting point, this change eliminated the problems identified for the Tier 1 parts supplier as being pinned between cars (OEM) and materials.

Regarding player roles within a team, students felt that the CEO had too much power, and that certain roles were not as fun as others. To change this outlook, teams were reduced to two players. The CEO and Research and Development roles were combined into a single role (R&D), and the Waste Manager and Production Manager combined to form the second player's role (Production). For each company in the supply chain, there are only two (2) roles in the computer-based simulation. These roles correspond to the decisions that each player is responsible for during each turn. The role of the R&D player is to make Innovation upgrades using the technology tree discussed in Section 3.2. The role of the Production player is to make the economic decisions about buying and selling. Both roles play a key part in raising the "green score" of their tier and supply chain.

The "green score" was implemented as an additional means to score the game beyond profitability. The overall winner is determined at game end based on an algorithm that includes both the total assets of each supply chain, but also the overall green score. The green score can be increased by both technological innovation and good waste management practices. This addition was made to shift the focus of the game away from a pure profit mode and thereby allows consideration of the environmental attributes of product manufacturing.

The Current Event card system used in the board game was a valuable way to add more realism to the game. Use of actual events that students might have heard about on the news – or even during a cooperative education experience – would provide a new level of connection. However, the students felt that these cards caused harsh effects only to certain teams, making the luck of the draw as important as any strategic play. The change to the orientation of the supply chain is likely to help assuage this issue, along with requiring that the same Current Event be applied globally to any competing supply chains.

3.2 The Innovation System

The major educational component in the game, with respect to engineering and the environment is the Innovation System or technology tree. This tree allows students to see how technology impacts the environment and what technologies are currently in use in the industry. The feedback taken from students was that it was too easy to choose the technology upgrade based on economic factors alone. Also, there were too few choices of technological innovation with no full tree layout available for effective planning. For the computer-based simulation, the technology tree was completely redesigned.

The Innovation System was the most interesting and compelling part of the board game. It was necessary to keep the educational aspects in mind during the redesign. With the new game length of ten (10) rounds, there were numerous possibilities for redesigning the tree. The very first change made was to remove the ability to upgrade technologies in more than one area of specialization (i.e., innovation in storage, production and waste) within a round. There is now only one (1) technology upgrade allowed per turn. There was also a change made so that in the final turn, there is no technology upgrade since the teams will be getting ready to sellout.

The different areas of technological specialization were retained from the board game: storage, production and waste. A new enterprise was included that would allow players to strategize and plan ahead. After six (6) turns and strategic planning for the right combination of upgrades, the team can reach a "Technology Mastery" in any given specialization. This technology gives significant bonuses to the specialization category. Due to the number of technology upgrades required, it would be impossible for any team to get more than one (1) Technology Mastery during the ten (10) rounds of play. This will allow for replayability if the students would like to try a different path when playing the game again.

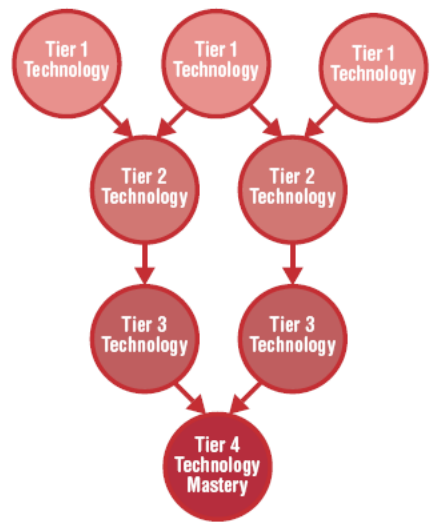

Figure 3 - Innovation System Redesign

Another slight change made to the Innovation System is for the Tier 1 part suppliers. The students that played on the parts team often felt that they had no control over the outcome of the game, because they relied directly on the materials and cars teams for all decision making. When the technology tree was redesigned, the Technology Masteries for Tier 1 parts suppliers all had an added bonus. This bonus not only increases the part supplier's abilities, but also impacts other tiers of the supply chain. By communicating on one team within the supply chain, it is possible to reach a maximum upgrade to one technological specialization. Essentially, parts suppliers will be able to strategize to give bonuses to the materials and cars company teammates, if they all choose to improve the same technological specialization.

3.3 Game Mechanics and Logistics

The board game was overwhelming to quickly understand for many players initially. There were several boards, dozens of game pieces, work sheets and Innovation cards. A clear issue was attempting to streamline and simplify the game play elements as much as possible, while not oversimplifying any element and maintaining academic merit.

With the use of computers to handle all the calculations rather than the players (supplied with calculators), additional rounds for the game became a reality. The new ten (10) round game allowed for more flexibility in content with long term goals becoming possible. This also gave the students more time exposure to Current Events (since one event occurs per round) and the educational content. Further, strategic planning for technological innovation in the board game was not conceivably possible within a simulated five (5) round duration.

The transition to a computer-based platform removed the need for chip swapping and other time consuming elements of the board game. There is also no need for a human game facilitator with the computer-based version, although having a facilitator / instructor present might provide assistance to students who are slower or having difficulty. The rounds in the computer-based game are not timed, so there is no problem with students that need a little bit of extra time. When the networking aspect is implemented in later versions the teams could potentially only play one (1) turn a day or class period, and the game could progress over several weeks or months. This tactic has worked well in medical education, where some simulations can last as long as several semesters [Lane et al. 2001].

Adding in an easy to access help manual that can be read at anytime would help to reduce the learning curve for students new to the game. Although not yet implemented, the idea of a tutorial or training round has been discussed and will likely be implemented in later versions. This would help students gain a more solid grasp of the game play mechanics and might reduce distractions to the learning objectives.

3.4 Drawbacks of the Computer-based Simulation

In making the change from board game to computer game there were some drawbacks. The interaction available through the board game at a team level is very valuable, but game play via a computer could be disruptive to seamless communication. The team boards allowed enough room to fit all four team members, however, a computer only allows a single person to have access at a time, which would reduce interpersonal communications (unless other internet communication systems were functional). An ultimate advantage of the use of a networked computer would allow creation of teams made up of students from around the world.

The loss of the human facilitator detracts from the flexibility of the game, which is not otherwise available in a computer-based environment. The computer can not allow for a "do over" or give the students a chance to take back and change a decision. This is excellent for governing game play, but can be frustrating when the students are just learning the game. After the students have grasped the intricacies of the game, the human facilitator merely slows down game play. The loss of this part of the game could prove advantageous in that students could potentially play unsupervised.

With all of the game boards visually available, the students could survey all of them. This is difficult to implement from an interface standpoint while trying to limit confusion. Designing the interface so that it is intuitive, but still provides a large amount of information was a challenge. Students really enjoyed the fact that the board game was organized and color-coded in such a clear manner. Giving focus on the computer allows for better concentration during the actual rounds of the game. This also forces the students to communicate more with each other to grasp the big picture.

The change from a four (4) person team to a two (2) person team limits the number of students that can play, (although in this first version of the computer-based game the team size is six – due to the fact that the entire three company supply chain plays as a team). Playing with a small team size also reduces the amount of communication and cooperation required on each level of the supply chain. This change does induce the need for student teams to communicate on the supply chain level, which is more important to the overall teaching goal.

4 Shortfall: Computer Game Play Testing

The prototype computer-based simulation will be tested in a Northeastern University engineering course with both undergraduate and graduate engineering students. The course, entitled "Environmental Issues in Manufacturing and Product Use" has fifteen students (nine graduate students and six undergraduate students) enrolled for the Spring 2007 term. The play testing will take place over two class periods in April, allowing time for the students to get a firm grasp of the rules and be able to play strategically.

In this version of Shortfall Online, there are two teams which each represent supply chains consisting of materials, parts, and cars. Each company in the supply chain is played by two players, making the total number of student players as 6 per supply chain team. The game will include at least two competing supply chains, possibly a third depending on attendance.

Each supply chain will be given a laptop. During the round, the students will pass the laptop around the supply chain team allowing each player to make their decisions. At the end of each round, the scores will be checked among the laptops to determine how the game is proceeding. At the end of the game, the team with the highest combination of profit and green score will be declared the winner.

With this current implementation, it will be difficult to have the same Current Event used for every supply chain. This difficulty may cause a balance issue, but without a networked implementation, there is no easy fix.

Similar assessment will be performed as for the board game to determine student learning, as well as student enjoyment of the experience. Student feedback will be obtained to help with refinement of subsequent game revisions.

5 Conclusions

The necessity to keep education technology on the cutting edge is a driving force to create video format learning simulations. Shortfall was originally created as a board game, but through assessment and analysis, the next logical step was to move to a computer-based platform. Although not a simple task, the first steps of the process have been outlined here. After the prototype has been completed and tested, additional work would be required to improve upon the learning opportunities in Shortfall. The addition of more teams and supply chains, adding a computer controlled supply chain, designing and testing interface options and making it available on the Internet would be the next logical steps in the evolution of the game.

In this version of Shortfall Online, there are two supply chains teams consisting of materials, parts, and cars. Each company in the supply chain is played by two players, making the total number of student players 6 per supply chain team. Adding more supply chains and teams would give the simulation a more "real world" feel, because of the level of competition in the real world automotive industry. Also the addition of a computer controlled supply chain would give players a baseline and also competition that is not open to control or negotiation. Finally, if the game could become available on the Internet, players and students would no longer need to be in the same room or lab to play Shortfall; it could be available whenever and wherever players wanted to play.

While Shortfall has only begun its metamorphosis into an online multi-user learning simulation, the foundation has been laid. Assessment and follow-up on student comments after playing the prototype board game suggested methods to best leverage technology as we developed Shortfall Online. An assessment of the advantages as well as limitations that this iterative digital version introduced compared with the board game will be key in our development process. Shortfall was designed to raise environmental awareness of engineering students through game play, and we anticipate that testing and development of multiple iterations of screen-based digital versions will allow us to ultimately design a game that allows better understanding of engineering and social issues on a complex relational systems level.

Acknowledgements

The authors would like to acknowledge the support of NSF grant number DMI-0537056 and are grateful to D.M. Qualters, T.P. Cullinane, J.C. Benneyan, K. Wilcox and A. Torabkhani for efforts on other aspects of this game.

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ID - vgsp_0034