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STEM Learning Games and Game Design in ITEST Projects

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In a rural California district, girls gather with friends after school to collaboratively program arcade-style computer games. Middle-schoolers, high-schoolers, and college students in Colorado design games in challenges adapted to their skill levels. In two different U.S. metro areas, 1,300 high school students use a game-based system to explore STEM interests and learn more about pursuing STEM in college and beyond, winning real-world campus visits for high achievement in the game. All of these youth are participating in ITEST projects centered on STEM learning games and game design.

To share promising strategies in student-focused ITEST experiences with the ITEST community and the STEM education field, the ITEST program has called for reflection on best practices and lessons learned in response to the question, ***"What coherent sets of experiences effectively and efficiently support student competency (e.g., knowledge, skills), motivation, and persistence for productive participation in the STEM-related workforce of today or***

The Innovative Technology Experiences for Students and Teachers (ITEST) program was established by the National Science Foundation (NSF) to help ensure the breadth and depth of the Science, Technology, Engineering, and Mathematics (STEM) workforce, in direct response to concerns and projections about the growing demand for and current shortages of STEM professionals in the U.S. The STEM Learning and Research (STELAR) Center at Education Development Center, Inc., in partnership with the Goodman Research Group, Inc., assists ITEST principal investigators (PIs) and evaluators to design, refine, and evaluate their ITEST projects and to effectively synthesize and disseminate project findings.

in the future?" We address that question in this paper by focusing on ITEST projects that center on STEM learning games and game design.[1]

Games can replicate local conditions, involve real-world problems, or simply feature appealing designs or plot lines to help students perceive STEM learning as relevant and meaningful to their own lives.

This paper is based on a review of over 200 publications relating to 110 ITEST projects. Within that set, we identified publications relating to 12 projects that involve STEM learning games and game design experiences for students. The publications demonstrate that game-centered projects have been a constant feature in the ITEST portfolio, from the 2003 start of the program to the present. Further, game-centered projects have been one of the three most prevalent forms of student-focused ITEST projects, along with robotics experiences and projects using mapping technologies such as GIS and GPS. Most game-centered projects focus primarily on students (including pre-service teachers in teacher training programs) and feature some teacher involvement. They take place in both in-school and out-of-school settings, including afterschool and summer camp environments.

Games can replicate local conditions, involve real-world problems, or simply feature appealing designs or plot lines to help students perceive STEM learning as relevant and meaningful to their own lives. The Improved STEM Preparation Through Humane Gaming project (2006–2011) involved students designing "humane games" with medical or societal applications (e.g., containing illness by mapping an epidemic; connecting victims of a natural disaster with various services) as a way of giving students a voice in real-world issues (Austin, Leutenegger, & Fajardo, 2009). Other projects seek to make STEM learning more relevant by taking cues from representations of STEM professionals in popular culture—for example, by using forensics-focused mystery games to engage students who are familiar with television crime dramas in learning biology concepts, a strategy employed in the HI-FIVES project (Highly Interactive, Fun Internet Virtual Environments in Science, 2005–2008) (Annetta, 2008). Although researchers in the Games Requiring Advanced Developmental Understanding and Achievement in Technological Endeavors (GRADUATE) project (2010-2013) found that modifying "serious educational games" increased student interest in science (Annetta et al., 2014), there has been some debate regarding whether such "serious games" can truly appeal to a broad range of students, including female, African American, and Hispanic students (Haller et al., 2008). A new turn toward culturally relevant gaming, as we address below, may help to counter such criticisms.

This paper summarizes reviewed publications related to game-based learning and game design in ITEST projects and offers a detailed look at a few more recent projects. We also include a summary of lessons learned to support the smooth implementation of future projects.

1 This is one of two papers that responds to this question. Authentic Inquiries into Local Issues: Increasing Engagement and Building a Sense of STEM Identity and Agency focuses on projects involving authentic inquiry into topics of local relevance.

Evolution in rationales for game-centered approaches

STEM learning games and game design address a wide range of ITEST project goals, including improving learner engagement, introducing complex concepts, and exploring computational thinking. Over the time period covered by the publications reviewed, the arguments made for using STEM learning games with youth have become more sophisticated, and the role of the game in the intervention has also shifted.

Publications from earlier game-based projects (i.e., prior to 2010) typically proposed that since many students play video games in their leisure time, they would find game-based STEM learning environments appealing and engaging (see, for example, Austin et al., 2009; Barko & Sadler, 2013; and Haller et al., 2008). Project teams also observed that players can find the immediate feedback provided by games to be motivating. Players' actions have direct consequences in the game environment, which also creates a safe context in which to take risks, develop ideas iteratively, and learn from failure (Austin et al., 2009; Hirsch, Carpinelli, Kimmel, Rockland, & Burr-Alexander, 2009; Rodger, 2007; Trocki, 2014). In addition, these publications noted that game environments can offer opportunities for embedding formative assessment. Today, these characteristics of games are well-known, and ITEST project teams draw on the most recent research regarding games and learning.

The new generation of game-centered awards tends to link gaming and game design with academic, affective, or aspirational goals, in addition to touting the potential for increases in engagement.

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This paper is based on a review of over 200 publications collected from research.gov and the STELAR website, and of additional resources related to newer projects. The publications reviewed relate to approximately 110 of the 325 ITEST projects funded from the program's inception in 2003 to 2015. The publications originally appeared in sources from a wide range of disciplines (ranging from maritime technology to women's studies) and an array of formats (research journals, practitioner-focused magazines and newsletters, and conference presentations and posters). The publications reviewed also contain widely ranging levels of detail, and the connection to a given ITEST project may be direct or tenuous. Many include descriptions of project implementation or implementation plans. A smaller portion describe targeted outcomes, evaluation methods, and findings.

This variety of information sources reflects the diversity of ITEST grantees' backgrounds, specialties, and professional communities, as well as the diversity of local contexts for which projects are designed. ITEST projects build on the strength found in bringing together diverse professionals in the goal of broadening participation in STEM careers, but this strength also presents challenges, in that ITEST PIs can come from a range of academic disciplines, the nonprofit sector, or formal or informal learning arenas. By summarizing available publications, STELAR hopes to facilitate learning across the various professional communities that together comprise the ITEST community.

Gameplay is combined with community and family engagement activities, connections to STEM mentors and role models.

For example, the project descriptions for two recent awards, the iDesign Culturally Relevant Game Design project (2013–2017)[2] and the Connecting Pre-Service Teachers and Urban Latino Youth project (2015–2018),[3] offer rationales for gaming focused on computer science principles and practices and computational competencies. In addition, ITEST projects involving learning games have increasingly focused on game design in recent years, giving students opportunities to engage with abstract computer science concepts through the game design process. Projects that involve game development can help participants build spatial conceptual thinking, computational thinking skills, and systems thinking (see, for example, Denner, Werner, Martinez & Bean, 2012a; Denner, Werner & Ortiz, 2012b; Denner, Bean, & Martinez, 2009; Rodger, 2007; and Werner & Denner, 2009).[4]

Another feature shared by several recent projects, presented in more detail below, is that the game itself is only one component of a much more complex, "wrap-around" intervention. In these projects, gameplay is combined with community and family engagement activities, connections to STEM mentors and role models, and other supports regarding students' STEM pursuits.

While approaches have evolved over time, certain benefits of game-based learning have remained consistent. Throughout the time period covered, proponents of game-based learning have posited that STEM-centered games and game design experiences can increase learners' motivation and interest in STEM pursuits, and help students perceive STEM as relevant to their own lives. In addition, project teams note, such game-based online environments can provide access to a wider array of pedagogical tools and approaches, such as simulations and virtual laboratories, than may otherwise be available in a middle or high school math or science course. The New Mexico Adventures in Modeling project (2003–2007) found that participatory simulations, in which students manipulate conditions to see different results, showed advantages for students in terms of motivation, engagement, self-directed learning, and problem-solving (Klopfer, Yoon, & Perry, 2005). Another project, Using Squeak to Infuse IT into the STEM Curriculum (2006–2009), found evidence that embedding games and simulations in the science curriculum can improve standardized test scores (Franklin et al., 2009).

2 For more about iDesign, visit the STELAR website (http://stelar.edc.org/projects/13521/profile/idesign-developing-technological-fluency-through-culturally-relevant-game).

3 For more about Connecting Pre-Service Teachers and Urban Latino Youth, visit the STELAR website (http://stelar.edc.org/projects/18377/profile/reciprocal-model-teaching-and-learning-computational-competencies-connecting).

4 For more on projects that involve game development, also see "About iDesign" at the iDesign website (http://www.nsfidesign.org/about-1/#about-idesign).

Partnering to provide game-based experiences that emphasize cultural relevance

Several ITEST awards, including some recent awards, incorporate gaming and game design within an overall effort to broaden the participation of underrepresented groups in computer science or STEM. The approach of providing culturally relevant STEM opportunities holds promise for increasing the participation in STEM of people of color and people in high-poverty communities, who may have few role models or mentors for their STEM interests and pursuits (Denner et al., 2009; Werner & Denner, 2009).[5] The projects highlighted below blend a focus on cultural relevance with gaming in their implementation approaches.

Mentoring Latino youth in game design

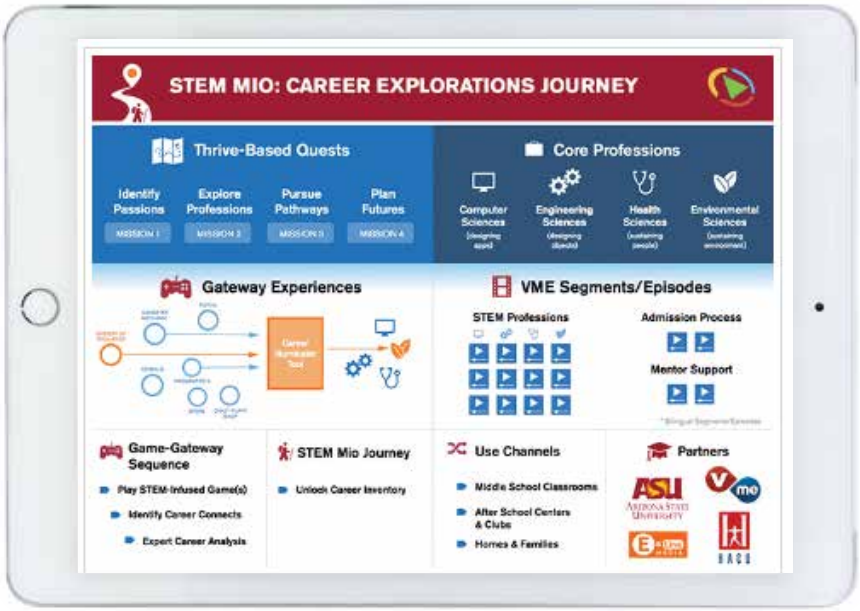
The iDesign project, led by Hofstra University in partnership with Global Kids and the New York State Afterschool Network, has participating students in grades 6–9 first select and research a topic that is important to them and their communities.[6] Students then learn about game design theory using Gamestar Mechanic, an online game-based environment for learning programming. Working with Scratch, a simplified programming language developed by the MIT Media Lab, the students are subsequently mentored in designing a game focusing on their chosen topic. The research and game design experiences take place in "clubhouses" that meet after school and during the summer. Participating youth also learn to mentor their peers and learn about STEM careers, including game design. A summer institute for teachers focuses on game-based and inquiry-based learning approaches.

The research on culturally relevant pedagogy posits that students from non-dominant populations may show increased engagement, and possibly greater learning outcomes, when academic content includes linguistic cues, values, and traditions from the students' communities (Diamond, 2015). This approach dovetails with the emphasis on local context characteristic of ITEST projects. In particular, iDesign actively seeks to engage youth from communities underrepresented in STEM, particularly Latino and African American youth, and PI Roberto Joseph has long been a proponent of incorporating culturally relevant design into educational technology (Benson, Joseph & Moore, in press; Joseph & Diamond, in press; Joseph, 2009; Joseph & Clark, 2009).

Providing culturally relevant STEM opportunities holds promise for increasing the participation in STEM of people of color and people in high-poverty communities.

5 Also see "A Reciprocal Model for Teaching and Learning Computational Competencies: Connecting Pre-Service Teachers and Urban Latino Youth" on the STELAR website (http://stelar.edc.org/projects/18377/profile/reciprocal-model-teaching-and-learning-computational-competencies-connecting).

6 For a more in-depth look at locally relevant inquiry experiences in ITEST projects, see Authentic Inquiries into Local Issues: Increasing Engagement and Building a Sense of STEM Identity and Agency. For more about iDesign, visit the iDesign website (http://www.nsfidesign.org/about-1/#about-idesign).



A game of STEM pursuits with real-world prizes

A new project, STEM Mio (2015–2017), has developed a game-centered approach to guiding Latino youth in STEM pathways. STEM Mio frames the pursuit of a STEM career as a set of "quests," "missions," and "challenges" that take place in the game environment and beyond. The game platform presents opportunities for players to explore and refine their STEM interests, and then to explore related course offerings and financial aid scenarios at various colleges and universities. Players who "level up" in the game can be selected to win an all-expense-paid visit to a campus of their choice.

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The game platform enlists participation not only from student players but also from their families and teachers. Gameplay dovetails with resources from partner organizations, such that the game is at the heart of a network of pathway support. STEM Mio is led by the Center for Games and Impact at Arizona State University, in partnership with game designers E-line Media, VME (Spanish public television), and the Hispanic Association of Colleges and Universities. VME also contributes a video series on Latino STEM professionals that provides role models for participants while also promoting STEM Mio to engage new participants.[7]

Implementation of STEM Mio is in beta testing in summer 2016. The team hopes to conduct full classroom studies and offer its first campus tours later this year (personal communication with Anna Arici, May 25, 2016). The project now involves 1,300 youth in two different metro areas and is recruiting participants from additional communities as it ramps up.

Multifaceted interventions

For both iDesign and STEM Mio, gaming is one component of a multifaceted intervention. Both projects marshal the resources of key partners and the community in conjunction with the game. Similarly, the Connecting Pre-Service Teachers with Urban Latino Youth project is working with both students and pre-service teachers to develop a new afterschool curriculum focused on computer competencies. In this experience, games are one of four programming components in the curriculum, which is designed to raise awareness of STEM careers, including gaming, and to improve participating pre-service teachers' capacity to teach computer science content. The computational explorations emphasize a real-world context for the participating urban Latino middle and high school students, with the goal of "relevant, engaging, and authentic learning (REAL)."[8]

7 For more about STEM Mio, see the Center for Games & Impact website (https://gamesandimpact.org/initiatives/stem-mio/).

8 From "A Reciprocal Model for Teaching and Learning Computational Competencies: Connecting Pre-Service Teachers and Urban Latino Youth" on the STELAR website (http://stelar.edc.org/projects/18377/profile/reciprocal-model-teaching-and-learning-computational-competencies-connecting).

Collaborative design experiences for rural Latina girls

An earlier project, the Girl Game Company (2006–2010), also focused on cultural relevance. The team behind it noted that girls from underrepresented populations may have a dual challenge in developing STEM identities—and therefore in persisting in STEM pursuits—since they often face contrary expectations from their families and communities regarding both their gendered and their ethnic selves. The Girl Game Company was designed to engage Latina middle school girls in programming games in an afterschool and summer-program format, while also developing support from peers, families, and other adults for the girls' computing interests. The program, which took place in a rural California district, drew 165 participants. The number of hours the girls spent in the program varied widely; 79 completed 50 hours or more, with some spending up to 250 hours during that time (Denner et al., 2012a; Denner et al., 2009).

The project employed research-based strategies to engage young Latinas by connecting participants with Latina STEM role models, supporting English learners, and soliciting involvement from families. The approach was designed specifically to appeal to middle school girls; for example, participants worked collaboratively, designing and programming games in pairs.

Students who participated for over 50 hours showed an increase in computing career goals, expectations for success with computing, the value they placed on computing and computing-related jobs, as well as perceived parent support (Denner et al., 2012a). The project also resulted in

findings about the conditions under which pair programming can be used to support learning with computers (Werner & Denner, 2009), and the important role of curiosity in sustaining learning and engagement in computing fields (Denner, 2011).

Survey results from 24 participants showed that connections with friends was among the girls' favorite aspects of the program, along with the creativity the program fostered and the online "offices," where the girls could store materials and share notes in the game design platform. Results also showed increases in participants' belief that their parents wanted them to attend college and pursue science or computing careers (Denner et al., 2009).

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Large participant pools and involvement over time

The 2013 Hour of Code Frogger 3D activity attracted nearly a quarter million participants in just one week.

Some game-centered projects have large numbers of participants—hundreds or thousands—while others involve smaller numbers of students over a longer duration, of one to three years. This section builds on the examples described above to further illustrate projects whose size and/or duration suggest a high level of potential impact.

The oDREAMS: Promoting Computational Thinking through Game & Simulation Design Scalable Game Design project (2013-2017) is exploring how to scale up teacher professional development when teaching Computer Science through game design approaches. Collaborating with the eMINTS National Center at the University of Missouri, oDREAMS has conducted, analyzed and compared face to face, online and blended teacher professional development approaches. Scalable Game Design is a curriculum that has been developed and validated to teach Computer Science skills through motivational game design activities. Teaching focusses on the acquisition of Computational Thinking skills in ways that they can be leveraged to later build STEM simulations. The notion of scalability refers to the gradual acquisition of so called Computational Thinking Patterns through the implementation of a series of increasingly sophisticated game replicas ranging from simple 1980 arcade style games such as Frogger to games including advanced Artificial Intelligence such as The Sims. A formal study exploring efficacy of teacher professional development has trained over 200 teachers participating with over 10,000 (mostly middle school) students (Repenning et al., 2014; Repenning et al., 2015). Informal Scalable Game Design participation has included the 2013 Hour of Code Frogger 3D activity which attracted nearly a quarter million participants in just one week.

Digispired: Digital Inspiration for Interactive Game Design and programming skills (2006-2009) worked with 90 middle school students over three years. Students were engaged in robotics and game design using Squeak and Alice. Eighty-five percent of the student participants completed the three-year experience (Ouyang et al., 2010). Students developed games focused on STEM concepts. For example, one student simulated the digestive system, while others worked on games modeling plant growth, virus propagation, and basketball movements during a game. A follow-up project, Digispired ii Workforce Investigation Inspiration for STEM (2010-2013), engaged 40 teachers and 60 students over a three-year period. Teachers participated in a

summer institute to familiarize themselves with the object-oriented programming language, Scratch, and the programming environment, Alice. Teachers then worked with the research team to support students in designing their own STEM-focused educational games. Students created games with Scratch, C# and Unity 3D. Twenty-five students participated in both projects; of those, 24 enrolled in four-year STEM college programs.

While a number of projects have used game design experiences for middle and high school students, the HI-FIVES project also used games and game design at the undergraduate level in a course for pre-service teachers. The course introduced future STEM teachers to a Multiplayer Educational Gaming Application that served both as a synchronous online environment for learning science content and as a programming environment where teachers could design and create 3-D role-playing games to supplement science education materials. Over 60 pre-service teachers completed the training to design their own games (Annetta, 2007). As these participants go on to bring game-based learning to their future classrooms, they will impact thousands of students.

Attention to contextual factors: Lessons learned to support smooth implementation

Game-centered projects for which we reviewed publications seemed as likely to take place in in-school setting as in out-of-school contexts—and some out-of-school-time projects took place at

schools and involved teachers and school facilities. Whether projects take place in or out of school, keen attention to contextual factors, from the earliest stages of implementation, can mitigate potential challenges. Several game-related school-based projects offered lessons learned in their publications, which we summarize here.

Obtaining buy-in from teachers and school leaders

Numerous ITEST project teams have realized that buy-in from administrators and teachers is of primary importance for smooth project implementation. Many teachers already feel constrained by a packed curriculum and may not be eager to take on an additional commitment. Sustained engagement with teachers and their students proved possible particularly in cases where teachers perceived a game-based intervention as addressing hard-to-teach concepts or concepts with which their students typically struggle. Teachers agreed that two key factors in supporting smooth implementation were (1) appropriately grounding the content

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focus of a game in the curriculum and (2) aligning the learning objectives to relevant standards.

One project team at first encountered resistance from administrators and schools but saw a great improvement in attitudes over time. By the end of a multi-year intervention, students were playing the game outside of assignments, and students at other schools had also begun to play (Ouyang et al., 2010). In another project, three years of data showed that embedding games and simulations in the science curriculum was correlated with an increase of 10-30% on the state science test—a finding that teachers valued (Ouyang et al., 2010).

Offering meaningful professional development to support student-focused projects

Substantive teacher professional development is de rigueur. Successful projects offered summer institutes and weekend workshops in which teachers could experiment with the game or programming environment their students would be using (Ouyang et al., 2010). One project offered a four-week program to help prepare teachers to facilitate a two-week game programming experience; in addition to practicing with the programming environments, the professional development included an introduction to computer science concepts and pedagogies (Al-Bow et al., 2009; Austin et al., 2009).

Taking teachers' experience and needs into account

By starting with a needs assessment, one project realized that teachers lacked experience with technology generally and with learning games specifically, and that many held negative attitudes regarding the use of computer games for educational purposes. Learning of these potential barriers up front allows projects to incorporate strategies to mitigate them into their professional development approaches and to plan appropriate ongoing implementation support. Needs assessments can also be valuable in surfacing such issues as scheduling constraints or infrastructure challenges that must also be taken into account. In some projects, computer science graduate students have been present in classrooms to support teachers and troubleshoot problems along the way.

Enlisting teachers as invaluable partners in data collection

ITEST teams conducting interventions in schools have relied on teachers to administer and collect student surveys, conduct observations, keep logs, and

complete and submit surveys themselves (Al-Bow et al., 2009; Austin et al., 2009; Franklin et al., 2009). Teacher recruitment and retention are thus key factors in project success. A participant cohort can shrink by over 100 students when a single teacher drops out, particularly in cases where the teacher has student participants from multiple courses. For a project working with one teacher at each of four schools, losing one teacher cost the project a quarter of its participants and one whole participant subgroup (Al-Bow et al., 2009; Austin et al., 2009). As we discuss in greater detail in the related synthesis on teacher learning,[9] attending to teachers' needs, perspectives, and the constraints of their contexts in project design can support teachers in committing to the duration of the project. In addition, incentives such as small stipends or course credits could be appropriate in some cases.

9 For a more in-depth look at ITEST projects that work with teachers, see Engaging Teachers in Supporting Next Generation STEM Learning.

Looking Ahead

From Palm technology to immersive online worlds and programming environments, the tools available for game-based ITEST projects (and the approaches used to implement them) have evolved over the years. Game-based learning and game design experiences align well with ITEST program goals in that they can provide opportunities to deepen STEM content knowledge and computational thinking skills, spark higher engagement with STEM studies, improve awareness of STEM careers, and offer environments in which to conduct authentic inquiry. Newer projects designed to engage members of underrepresented groups are now unfolding. These new projects challenge one of the last remaining negative perceptions of game-based learning: that it will appeal only to a narrow slice of the student population. The ITEST community and the broader STEM education community eagerly await the new findings in this area.

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Projects included in this synthesis

(listed in order of appearance):

1. Improved STEM Preparation Through Humane Gaming (2006–2011; DRL-0624767)
2. Highly Interactive, Fun Internet Virtual Environments in Science, HI-FIVES (2005–2008; DRL-0525115)
3. Games Requiring Advanced Developmental Understanding and Achievement in Technological Endeavors (GRADUATE) (2010-2013; DRL-0833452)
4. iDesign Culturally Relevant Game Design (2013–2017; DRL-1312240)
5. Connecting Pre-Service Teachers and Urban Latino Youth (2015–2018; DRL-1433440)
6. New Mexico Adventures in Modeling (2003–2007; DRL-0322573)
7. Using Squeak to Infuse IT into the STEM Curriculum (2006–2009; DRL-0624615)
8. STEM Mio (2015–2017; DRL-1433837)
9. Girl Game Company (2006–2010; DRL-0624549)
10. oDREAMS: Promoting Computational Thinking through Game & Simulation Design (2013–2017; DRL-1312129)
11. Digispired: Digital inspiration for Interactive Game Design and programming skills (2006-2009; DRL-0624565)
12. Digispired ii Workforce Development (2010–2013; DRL-0929521)

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Suggested reference:

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