A Classification Scheme for Gamification in Computer Science Education: Discovery of Foundational Gamification Genres in Data Structures Courses

1st Adam Spanier
Cyber Systems Department
University of Nebraska at Kearney
Kearney, Nebraska, USA
spanieram@lopers.unk.edu

2nd Sherri Weitl Harms
Cyber Systems Department
University of Nebraska at Kearney
Kearney, Nebraska, USA
harmssk@unk.edu

3rd John Hastings
Cyber Systems Department
University of Nebraska at Kearney
Kearney, Nebraska, USA
hastingsjd@unk.edu

***Abstract*—This research full paper presents two main outcomes: 1) a novel classification system for gamification implementations including proposed genres, and 2) a comprehensive study and categorization of existing DSA gamification applications and a discussion of genres absent existing applications. Gamification presents a great potential to improve user engagement, motivation, and learning in nearly all fields of study including computer science (CS) education. However, it lacks formalized study and comprehensive analysis in CS education, and thus what makes for effective gamification is still a key question. Rather than initially trying to examine and catalog existing gamification applications and studies across the breadth of CS education as a whole, this paper instead focuses on Data Structures and Algorithms (DSA) courses. In general, DSA courses tend to be difficult due to the inherent complexity and abstraction exhibited by the fundamental concepts. As such, gamification presents a potential opportunity to convey these complex ideas in meaningful and unique ways.**

To carry out this work, a literature review of current DSA gamification applications is presented, the applications are categorized, and the pros and cons analyzed. Based on this analysis, a classification system is created and two new abstract genres are identified: dynamic gamification and collaborative gamification development. Potential uses, benefits and detriments are suggested for these newly identified genres. With this analysis and classification of gamification along with the identification of new abstract genres, the practice of gamification in DSA coursework can be made more efficient and effective. Upon a more thorough understanding of DSA gamification, pedagogical considerations can be made to better aid teachers and instructors in the integration of gamification into existing curriculum. The paper also touches on the applicability of the classification system to CS gamification examples outside of DSA.

***Index Terms*—Undergraduate Computer Science Education, Pedagogy, Active Learning, Computer-based instruction, Gamification, Qualitative Study**

I. Introduction

Innovative technologies such as virtual reality, augmented reality, three-dimensional graphics, and advanced computational modeling continue to drive improvement in industries including medicine [1], engineering [2], social sciences [3], and education [4]. Computer science (CS) assists numerous disciplines through the creation of innovative solutions [5] including educational tools. While these educational tools are readily implemented in other fields of study, it is also essential to integrate these tools into courses meant to instruct future computer scientists [6]. Various approaches such as student-led projects [7] have been used to embed innovative technologies into the CS curriculum so that students learn innovation by doing without necessarily being aware they are engaged with systematic processes [8].

While concepts such as virtual reality and interactive content can provide student success improvement through novel approaches to sharing information, the use of such technologies in the strictest sense can miss a major factor in student aptitude improvement: motivation. As a means to add motivation to the above stated tools, gamification provides a means by which innovative technologies can be gathered together and implemented to increase student interaction [9], [10].

Gamification, "the use of design elements characteristic for games in non-game contexts" [11], is an innovative approach that currently presents a great deal of potential in education. As a practice in modern technological terms, gamification finds itself at the intersection of many of the most innovative technologies available today. By utilizing elements such as augmented reality, virtual reality, immersive technologies, interactivity, 3D graphics, visual interfaces, auditory stimuli and feedback, and other sensory interactions, gamification is poised as a means by which innovative technologies can be readily applied to CS education as a whole.

Data Structures and Algorithms (DSA) courses are arguably the most important for undergraduate CS majors [12]. Not only is the material foundational in nature (in preparation for later courses), but also in technical job interviews, potential candidates are often expected to solve problems that directly relate to DSA concepts [13]. It is thus essential that students be equipped with the best possible understanding of course concepts. DSA courses tend to be difficult due to the inherent complexity and abstraction exhibited by the fundamental concepts, and thus present an educational challenge, but also an opportunity for innovative approaches such as gamification.

While being mindful of the potential benefits of gamification across the breadth of CS, this paper focuses on gamification in DSA due to the aformentioned criticality of the course, and presents two main outcomes: 1) a classification system for gamification implementations including proposed genres and 2) a comprehensive study and categorization of existing DSA gamification applications and a discussion of genres absent existing applications. The paper also touches on the applicability of the classification system to CS gamification examples outside of DSA.

The rest of this paper is organized as follows. Section II details the background and key concepts concerning gamification in general, modern gamification, and gamification in DSA coursework. Section III presents the research questions used to evaluate current DSA gamification applications and to develop a classification system. Section IV outlines the classifications derived from the literature review. Section V presents the implications, benefits and detriments of the existing and newly identified classifications. Section VI outlines potential future research, and section VII presents the conclusion reached through this study.

II. Background

The use of games as a pedagogical tool in the classroom is "at an all time high, with more educators than ever using games for learning in their classrooms" [14]. As a discipline in education, gamification has existed for thousands of years. As far back as 643 BC, Plato advocated play "to be necessary for education, as he saw it as a first step on a ladder towards true knowledge" [15]. During the enlightenment when education and learning were revived with vigor, Renaissance educators turned to the ideas outlined by Plato two millennia earlier. Vittorino espoused ideas that included the use of games in mathematics, even so far as attributing such a practice to the ancient Egyptians [16].

Though gamification has existed for millennia in education, the application of digital gamification is fairly new and significantly less developed. According to Alok Pandey, the earliest proposed usage of digital games as a means to supplement education occurred in 1961 when a French sociologist named Roger Caillois published a paper called *Man, Play and Games*. In the paper, Caillois "describes several social structure as sophisticated forms of games and identifies many behaviors as a form of play" [17]. This supposition was first applied after "Mark Lepper (1975) and Thomas Malone (1981) first separately presented their analyses of why computer games are engaging and stimulate intrinsic motivation" [15].

The first practical examples of the theories presented above "entered the classroom in the 1980's during the CD-ROM era" [14]. These games presented the first actual taste of just how digital technologies would change gamification applications in education. The advent of digital video games revolutionized the application and usage of games immensely, quickly becoming one of the biggest and most successful industries throughout the late 20th and early 21st centuries. Would the same revolution hold true with the use of digital games in the classroom? Could games meant only for recreation be repurposed and implemented effectively in educational settings? Only time would tell.

As a discipline, gamification didn't see widespread adoption until the second half of 2010 [18]. In terms of modern use, "gamification is not quite creating a game but transferring some of the positive characteristics of a game to something that is not a game, thus, gami-"fy"-ing. Those positive characteristics of a game are often loosely described as "fun", and they have the effect of engaging game players in the activity" [18]. In an attempt to associate learning with these "fun" attributes, gamification became a means by which educators dreamt of teaching students more effectively while eliminating the droll monotony of traditional education.

The use of gamification as a tool to better convey confusing and complex information demonstrates numerous advantages when training future computer scientists, programmers, and software engineers. CS is hard [19], and any tool that can be used to alleviate difficulties in conveying information effectively must be utilized to increase retention in CS programs. As it is, CS degrees "have the highest number of students dropping out, according to the latest figures from the Higher Education Statistics Agency (Hesa)" [20]. According to Hesa, 9.8% of all CS undergraduate students will drop out before completing their degree [20]. At the same time, the demand for CS professionals continues to rise. "According to the U.S. Department of Labor Bureau of Labor Statistics (BLS), the computer and information technology field is expected to grow by 13 percent from 2016-2026 – faster than the average growth rate of all occupations" [21]. This tendency to lose students, combined with a need to generate more graduates necessitates a creative and innovative approach to teaching CS students [7], [22].

Gamification isn't a new pedagogical tool in CS courses [23]–[29]. Whether it be a graphic implementation of a quiz app [25], [26], a means to facilitate socialization [28], a gamified learning experience [23], or any number of applications using game mechanics to facilitate learning, CS courses, in general, are rife with examples of gamified applications as a means to engage and educate potential students.

As an essential subset of CS education courses, DSA classes present a series of innately complicated and difficult to understand ideas. Due to this complexity, these courses present many students with more than enough impetus to switch degrees. According to García-Mateos and Fernández-Alemán, "There are two main causes of dropout: the implicit complexity of the matter, and a lack of motivation among students" [30]. It is due to this inherent complexity that DSA courses present one of the more opportune chances to utilize gamification for the benefit of CS students. According to most gamification applications in CS, engagement is the prime motive for its use [23]–[29]. The fact that gamification allows students to readily engage eliminates half the causes of dropout as stated above. Further, gamification as a practice can also be utilized to teach students more effective learning behaviors in order that complex ideas can be more readily absorbed [26]. By enabling students to better comprehend the innately complex ideas within DSA, the "implicit complexity" [30] referenced above can be significantly mitigated in order that students no longer feel the need to change degrees.

III. Research Questions

For organizational purposes, all research questions have been assigned to one of four broad categories to better facilitate the evaluation of gamification technologies in DSA courses. These categories are: A) Examples, B) Classifications, C) Impact and, D) Conclusions

A. Examples

- What are recent examples of gamification technologies used in DSA courses?
- How have these examples been used?
- Why were they implemented?

B. Classifications

- What are the primary characteristics and patterns evident in DSA gamification implementations?
- What characteristics and patterns naturally describe a unique classification?
- How do the above examples fit into these classifications?
- What are possible missing classifications?

C. Impact

- What are the benefits of the implementation of gamification technologies in DSA courses?
- What are the detriments?

D. Conclusions

- What are the general deductions and conclusions resulting from this study?
- Does the classification system potentially fit for CS education as a whole?

IV. DSA Gamification Classification System

In order to properly understand the current state of gamification in the DSA world, a comprehensive study of existing digital implementations, experiments, and interventions in DSA coursework was undertaken, utilizing the research questions identified above. Much like Linnaeus' classification of biological organisms [31], similar characteristic patterns naturally create groupings among applications. Upon the discovery of these patterns, each pattern received a name and was given its own unique genre. Similar to the adaptations that were made within the scientific classifications of biological organisms, as more DSA applications were observed, the classification criteria defining each genre were refined to best fit the data collected.

During this study, three distinct patterns emerged: 1) many of the applications utilized visualization to describe abstract ideas, 2) several applications added a gamified interface to a quiz or exercise program, and 3) the rest of the applications utilized ideas concerning social and collaborative engagement. Each application was subsequently scored based on its most significant characteristics and placed in the most applicable category. (See Table 1 for the description and classification of existing applications.) These unique categories comprise a novel classification system for DSA gamification.

The genres identified and named in this study are: 1) **Visualization of Abstract ideas (VAI)**, 2) **Enhanced Examination (EE)**, and 3) **Social and Collaborative Engagement (SCE)**. The majority of the applications reviewed fall into the VAI genre. This genre yielded four examples. EE yielded only two and SCE yielded two more. The two examples in the latter genre also exhibited significant characteristics of the VAI category thus bringing the total in that category to six. Overall, only eight rigorously researched DSA gamification applications currently exist. This number provides an indicator that DSA gamification remains underdeveloped and in need of further research. Further, the lack of equal distribution of DSA gamified applications in the above stated genres indicates a high level of homogeneity among DSA gamification applications. The sections below provide an introduction to the identified genres along with a brief overview of each gamification instantiation found within that genre along with its relation to the genre under which it was assigned.

A. Visualization of Abstract Ideas

Due to the complex nature and functionality of concepts such as search algorithms, graph trees, red/black trees, and other data structures, the ability to effectively visualize data structures and algorithms and their associated processes can allow students to understand ideas that without proper visualization would be difficult to comprehend. Digital gamification, as an inherent benefit, can allow instructors to effectively and flexibly demonstrate a step by step walk-through of algorithms and processes. In this way, students can better access the discrete operations of these concepts by clicking through or providing input to the decision structure of any given algorithm or data structure, thereby better comprehending just what happens when data is either added to, removed from, or processed by the algorithm or data structure being studied.

The first example analyzed in the VAI genre is Beckwith et al. [32]. In their attempt to understand the benefits and detriments of gamification in DSA coursework, they created a web-based game where players utilize clicking to manually progress through the processes used to implement a binary search tree data structure. The game was designed to allow "the student to quickly pick up information without being overwhelmed" [32]. Initially, students learn the mechanics by which connections are established, how nodes are related, and how the search is setup. Players then click along the correct path to find a given value. This step by step progression through the tree helps students understand the mechanics involved in searching, inserting and deleting values by visualizing each node, the connections between, and the functions involved in updating the structure. 73% of the participants enjoyed the game and 47% felt the game was more effective than traditional instruction.

A gamification application called *Cosmo Game* was designed to help students understand the mechanics behind the linked list data structure [33]. In the game, players help the main character, named "Cosmo", build bridges across each stage. Each bridge represents a linked list, and each node of the list is represented as a rock platform. The values of each node are presented as a graphical glyph presenting values wrapped in speech bubbles. The game provides a limited range of actions analogous to the actions of forming, rearranging, adding to, and deleting from a linked list. During game play, students work through the formation and modification of various lists in order to achieve the final goal. By visualizing linked lists as bridges, the *Cosmo Game* makes the abstract ideas found in linked lists more accessible to students.

Sort Attack, a game developed by Yohannis et al. [34] demonstrates the functionality of various search algorithms by visualizing them using a graphical interface. After completing a tutorial, players apply their knowledge by manually sorting lists of unsorted numbers utilizing a particular algorithm. These lists are presented on screen as an unordered array of rectangles. These rectangles are then reordered through the kinesthetic function of dragging and dropping. If an incorrect action is taken, the game will present the student with feedback and help them to understand what step should be taken instead. Yohannes et al. [34] present their explicit intention to visualize algorithms for the benefit of comprehension in their statement, "the abstract concept of sorting algorithm has to be visualized to make it more concrete" [34].

The final example we reviewed for this genre was less an implementation of a visualization application and more a model by which visualization applications could be developed and instantiated. In an attempt to create a generic model by which gamification could be accomplished in the instruction of sorting algorithms, Chirila et al. [12] developed a model that uses "an interpreter that takes both the algorithm and generated data as input and then interprets each step of the algorithm." In this way, any algorithm could be instantiated into a gamified app simply by providing the algorithm and the data set on which it would be implemented. The main impetus behind this attempt was due to the recognition that manual programming for applications that follow the same general patterns could potentially be instantiated in a way that uses these patterns to create a more streamlined and efficient means of implementation.

B. Enhanced Examination

As a more traditional application of gamification, the use of digitally enhanced examinations provides a more graphically attractive and interactive means by which to examine the knowledge a student possesses. Tests and quizzes by their very nature tend to be tedious and disengaging. In an attempt to better engage students with the content of an exam, an aesthetic appeal and a more interactive interface is added with the intention that students will better interact with the material.

The first example reviewed within the Enhanced Examination genre was a quiz application implemented by Dicheva et al. [35]. The application utilized the *OneUp* gamified course management system which provides a framework to enhance quiz and examination structures with embedded game mechanics. Dicheva et al. created "64 warm-up challenges with a total of 290 problems" [35]. The problems were then split into specific subject-based categories pertaining to Java, recursion, lists, trees and other data structures. Avatars, badges and a virtual currency were employed to enhance the examination process and allow students to better engage with the material. Students could earn and spend virtual currency on rewards including buying extra credit points, getting more time for a test, buying a homework re-submission or getting a different problem. The use of badges created little to no effect on student motivation. Virtual currencies created a great deal of motivation due to its direct effect on students ability to buy extra credit and extend deadlines.

Though course management software such as *OneUp* may provide a great deal of flexibility in achieving enhanced examination, it can also present some difficulties in its use, including the installation of associated applications and resources. An alternate approach involves utilizing simpler, more generalized technologies such as web-based or mobile apps which can require less preparation for use. One such example is a quiz application created by Barriales et al. [36] using *Kahoot* which is "a gamification tool created under this new method of teaching and meets all the necessary elements a game needs: mechanics, dynamics and components" [36]. By using *Kahoot* as a framework to build quizzes based on DSA course materials, they hoped to achieve a higher level of motivation and participation in the quiz experience while avoiding the innate complexities systems such as *OneUp* present. In general, their use of *Kahoot* as a supplementary form of examination garnered a positive reaction from the students that participated and, as an added benefit, didn't require a significantly larger amount of preparation.

C. Social and Collaborative Engagement

The use of SCE effectively facilitates student learning and motivation as they are being exposed to complicated ideas. In this way, gamification applications can be developed by which students can more easily interact with each other in ways that can augment student motivation and engagement. This genre represents the reality that students, by nature, are social beings. To encourage or otherwise use this innate attribute for the benefit of education has been a motive since the onset of progressive education. Modern digital attempts to harness this reality are no different and no less valuable.

In one of the more involved gamification implementations, Grivokostopoulou et al. [37] created a VR environment, *VR-ALGO*, where students interact with each other and their surroundings in order to better understand search algorithms. Though this implementation also falls well within the parameters of the visualization genre above, the use of social tools as a supplement to these visuals placed the application more accurately in this category. In *VR-ALGO*, users, as avatars, move freely in the world, actively engaging other avatars. Each avatar can also visit locations where exercises are carried out, examine and interact with 3D objects, study related materials, and take quizzes. *VR-ALGO* also presents virtual classrooms that "can support tutors' lectures to groups of students and simulate at some degree the physical classrooms in a real school" [37]. Beyond the classrooms used for lectures and tutoring, *VR-ALGO* also implements a virtual library where students can lookup and study all of the search algorithms included in the game. During the actual search algorithm exercises, each student works through different interactive and immersive visualizations of various search algorithms. In this way, "students can solve problems in mazes by correctly applying specific blind or heuristic search algorithms" [37]. The students felt very positive about the VR environment and the implementation of this VR application revealed a considerable increase in engagement as well as student comprehension.

The final DSA gamification application we reviewed also fell into both the visualization and collaboration genres. In an attempt to better teach students the complex functionality of the LR Parsing Algorithm, Zhang et al. [38] created a digital card game called *Into the Stack* by which 4 players utilize the LR Parsing Algorithm to reduce their hands and attempt to win the game. Players are dealt cards and then choose from four actions: draw, pick, deal, or grab. The game is won when a player reduces their hand to only one card and one joker. The goal is to help students visualize how the LR Parsing Algorithm takes in data, parses it, and subsequently places it into an organized structure. In *Into the Stack* four different students work together to understand just how the algorithms works, and in this collaborative capacity, it is hoped students can create a better comprehension of just how the mechanics of the algorithm work. According to Zhang et al. [38], the use of the game "can make the algorithm more vivid and intuitive, which would encourage students' interest in learning, enhance their confidence and stimulate their enthusiasm." The feedback from the students was positive.

D. Newly Identified Abstract Genres

In the study of existing DSA gamification applications, their characteristics, and the advantages/disadvantages they present, it cannot be understated that the existence of DSA gamification applications is limited. Where other disciplines provide a large number of studies and applications that can be utilized, DSA specific gamification, due to its inherently novel nature, presents very few existing examples that can be readily studied. Because of the novelty of DSA gamification and the subsequent limits in terms of available applications, it can be inferred that DSA gamification as a whole must present a number of missing or underdeveloped genres.

By carrying out a comprehensive literature review, it was the intention of this paper to glean as much data as possible pertaining to existing DSA applications in order to recognize broad patterns in the actual implementation of DSA gamification. In the three genres of existing applications it can be seen that the typical intent in DSA gamification is to 1) visualize, 2) socialize, and 3) enhance. Because an intentional study of current DSA gamification genres has yet to be carried out, the intent of most DSA gamification applications falls in the realm of intuitive development. Previous researchers who presented DSA gamification applications have noticed the most obvious benefits presented by DSA gamification and developed applications to fulfill these advantages. Where little harm comes from implementing DSA applications catering to these existing genres and their most obvious benefits, the lack of intentional study of patterns in DSA gamification has created a few notable holes in existing DSA gamification research.

Missing classifications in any classification structure are those areas that don't appear as readily and won't be discovered intuitively. Essentially, without an intentional attempt to find holes in the classification structures of existing DSA gamification applications, these missing areas will remain undeveloped. It is only with a better understanding of the efforts currently in existence that new classifications can be discovered that future researchers can explore and understand.

In the study of current DSA gamification applications, the most notable missing genres include the following:

- Dynamic Gamification
- Collaborative Gamification Development

Dynamic Gamification

Dynamic Gamification (DG) pertains to all gamified apps that dynamically change according to student input throughout their gamified life-cycle. Unlike more static implementations that, while exhibiting different curricular objectives, present a more or less static set of aesthetic and operative characteristics, DG would utilize student-led software development [7] using existing and novel data structures and algorithms while providing opportunities for students to be creative. In implementation, DG would still exhibit the same sorts of game mechanics applied in other gamification applications (e.g. leader-boards, avatars, badges, awards, graphical interfaces, missions, objectives, etc.), but would add a layer of student-led game development. The student-led innovations within a given game framework would dynamically shift the look, feel, game mechanics, and the overall set of characteristics exhibited by a given gamification app in order to cater to what the students feel would be most beneficial. In this completely dynamic environment, students can take ownership of the gamification experience and make it as fun and engaging as they desire. Additionally, depending on the application, DG can manifest a realistic software development experience. This realism can help students not only learn the concepts, but also self actualize in terms of seeing themselves as software developers.

Suggested uses of DG include but are not limited to: 1) student engagement in dynamic development and implementation of gamified applications, 2) improving the learnability of languages through student modified games, and 3) the creation of student defined pedagogical environments through the use of dynamically defined gamification.

Collaborative Gamification Development

Collaborative Gamification Development (CGD) pertains to all applications that utilize collaborative student involvement in the formation of the gamification framework. The development of the framework by the students participating can add yet another level of gamification customization that can offer a far more accommodating environment and help keep students motivated and engaged. Rather than simply being passively exposed to a given gamification application, students get to participate in the conceptualization and development of the framework by which the application is implemented. Again, CGD applications must exhibit some of the same gamified game mechanics in order to fall within the purview of gamified applications, but given that the application is gamified, the collaborative development of the gamified application causes the game to be considered CGD. CGD is particularly useful as it keeps the instance of a given gamification application fresh and directly formulated for the needs of a given set of students. This category is differentiated from DG by the fact that the framework of the application is created through a collaborative student-led process. CGD applications can exhibit DG characteristics within the scope of the collaborative development process, but DG is applied to the active implementation within the gamified application, where CGD is applied to the development of the gamified application itself. At the same time, DG doesn't require collaborative involvement. Each student can shift their individual domains irrespective of other student input.

V. Implications and Impact

The in-depth study of DSA applications revealed three existing but unnamed genres and two newly identified abstract genres. Benefits and detriments of each category will be explored. As a caveat, it is left to practitioners to ensure benefits are maximized and deficiencies are minimized.

The DSA specific genres could potentially apply to the broader discipline of CS education, given appropriate tailoring. However, a contextual analysis of CS education gamification applications must be conducted to determine if the classification system created in this study fits a broader scope.

A. Benefits Noted in Instantiated Gamification Genres

In general, motivation and engagement are the most typical advantages provided by the use of gamification in DSA education [23]–[29]. In the applications reviewed specifically involving DSA coursework, a generally positive perception was noticed as students evaluated the applications.

DSA gamification applications falling in the VAI genre tended to have a high level of approval. Beckwith et al. [32] saw 73% of the players enjoy the game while nearly half of the students surveyed saw the game as more effective than traditional instruction. Though student perception is important as an indicator of successful engagement, an understanding of how gamification affects performance must also be taken into consideration. In *Sort Attack*, the gamification application implemented by Yohannis et al. [34], the visualization of sorting algorithms helped students perform better on initial testing as opposed to students learning in a more traditional manner.

DSA gamification applications falling in the EE genre tended to have a high level of approval as well. Barriales et al. [36] found that gamification as a teaching tool significantly influences the learning process of introductory algorithms. While both engagement and performance are important benefits of gamification, motive is yet another factor that can be boosted in the implementation of these applications. The most significant example of such an effect was seen in the *OneUp* quiz app created by Dicheva et al. Though the use of badges and avatars was implemented, the study found that neither element created a significant change in student behavior in this particular study [35]. What the study did find was that the use of a virtual currency as a means by which students can buy rewards motivated the students significantly. At this point, it must be stated that the means by which this idea was implemented create the effectiveness of the the outcome. Rather than allows students to buy trivial objects, toys, or other non-academic benefits, the virtual currency implemented in Dicheva et al. [35] allowed students to buy things of practical worth including extra credit points, homework resubmission opportunities, extra time for tests, and problem replacements [35]. Because the virtual currency created real, tangible rewards in terms of grades, students found a great deal of motivation to put in the work necessary to earn points.

DSA gamification applications in the SCE genre had many of the same benefits as applications in the previously mentioned genres. The VR environment created by Grivokostopoulou et al. [37] saw the same enthusiasm as noted in previous genres, as students surveyed felt very positive about the VR environment. Not only were they positive about the application because it utilized an innovative and exciting technology, the experiment saw a considerable increase in both engagement and comprehension.

Student performance as also positively impacted by the VR application developed by Grivokostopoulou et al. [37]. Students using the VR technology showed a 20 point increase in post use comprehension as compared to students who learned via traditional means.

Additionally, the current, more static, implementation scheme for DSA gamified applications presents a series of benefits that can potentially be augmented by adding an extra level of student-led interactivity inherent in the DG and CGD genres. This augmentation will be explored in section 6.3 below.

B. Detriments Noted in Instantiated Gamification Genres

While the benefits of gamification in DSA courses easily reveal themselves, there are still detriments that can be seen in the implementation of gamification applications. Though each study pertaining to DSA specific gamification showed an overall positive outcome, the contextual analysis of gamification as applied to CS education in general shows the possible deficiencies gamification creates. It is our estimation

TABLE I
GAMIFICATION APPLICATIONS IN DSA EDUCATION

Genre	Game Description and Purpose	Reference
VAI	A web-based game designed to provide students with a better understanding of the Binary Search Tree data structure through direct and visual interaction with data structure methods such as insert, delete, and sort.	Beckwith et al. (2018) [32]
VAI	*Cosmo Game* was designed to help students understand the mechanics behind the linked list data structure. By visualizing linked lists as bridges, *Cosmo Game* makes abstract linked list concepts easier to understand.	Kannappan et al. (2019) [33]
VAI	*Sort Attack* is a a graphical, highly interactive game created to help students visualize and learn complex sorting algorithms and work students through a step by step implementation of each algorithm.	Yohannis et al. (2015) [34]
VAI	A generalize framework that provides instructors with the ability to instantiate a gamified sorting algorithm application. The use of such a game model increases the interactivity of the education material with students and serves as a means to help algorithms instruction due to its flexibility and general usage properties.	Chirila et al. (2016) [12]
EE	*OneUp* is a gamified data structures quiz app that utilizes badges and a visual currency to motivate students to be engaged in data structures learning and to improve overall student grades.	Dicheva et al. (2019) [35]
EE	*Kahoot* is a gamified quiz application used as a means for students to learn and interact with DSA concepts and significantly influence the learning process of introductory DSA algorithms.	Barriales et al. (2020) [36]
SCE	*VR-ALGO* utilizes VR to create a 3D learning environment. Students as avatars interact with educational materials and other students, organize virtual classes, take quizzes, and perform different exercises.	Grivokostopoulou et al. (2016) [37]
SCE	*Into the Stack* is a card game developed to visually demonstrate the functionality of the LR Parsing algorithm.	Zhang et al. (2020) [38]

that, because DSA coursework is generally more challenging, gamification implementations are carried out with a greater degree of effort and only where they make the biggest impact. Further, DSA coursework by its nature demands that it be implemented in a very specific, highly visual manner. As a testament to this fact [12], [32]–[34], [37], [38] all utilize at least one form of algorithmic visualization to effectively implement gamification principles. Though it may seem counter-intuitive that a more difficult subject might be better served in gamification, it is exactly this difficulty that seems to create a better understanding of the problem at hand. In this sense, the specificity of DSA coursework provides researchers with a more limited and well defined domain of possible solutions. In the greater sense of CS education, any and all ideas tend to be valid and therefore can potentially be implemented. Because the domain of possible solutions is so much greater in general CS applications there exists a high probability that ineffective applications will be developed.

Typically, the most notable detriments in DSA gamification are incurred through incorrect assumptions made by researchers in choosing how to implement gamification for a given subset of students. Many of the most negative outcomes were caused simply by missing the mark in terms of what gamified elements would best serve the students involved.

Even so, gamification as a pure idea still presents a larger number of benefits than it does detriments. In fact, the most typical detriments observed in gamification applications have little to do with gamification at all. Rather, the most common cause for the failure of gamification application studies is the improper implementation of gamification. Though game mechanics are used and the ideas of gamification are implemented, the overall application doesn't seem like a game [24], [25], [27], [28]. It is in these types of applications that the most failure is seen. This brings to light an important point: if gamification is used, it must adhere to the spirit of what makes a game fun. What that spirit is has yet to be decided, but it must be more than wrapping a quiz in a digital container, adding color and graphics to a quiz, or moving some element of study online where it can be associated with pictures.

C. Benefits of the New Abstract Gamification Genres

The addition of gamified applications falling within the newly identified abstract classifications stated above (Dynamic Gamification and Collaborative Gamification Development) could potentially add functionality and benefit beyond what existing DSA gamification applications provide. Where typical, static gamification applications can provide a great deal of engagement and motivation, allowing students to be an integral part of choosing the gamified mechanics that appeal to them can potentially create a significant boost to the already heightened levels of motivation and engagement. Additionally, both DG and CGD are ways to implement student-led projects, which have been shown to increase intrinsic motivation [39] and student retention [7].

At the same time, DG and CGD applications can potentially avoid the detriments noted with existing static implementations. Many of the detriments explained in the detriments section above were incurred through incorrect assumptions made by researchers in choosing how to implement gamification for a given subset of students. Without invaluable student input, researchers must assume what gamified elements would work best for a given set of students. Through these assumptions, many gamified applications are found wanting in terms of their outcomes. Instead, the gamified elements of a given application would be allowed to dynamically evolve through the utilization of both Dynamic Gamification and Collaborative Gamification Development.

By applying the principles stated in each classification, gamified apps can automatically shift themselves to fit perfectly to any given set of student participants. In this sense, DG and CGD can provide a great deal of benefit. When researchers make assumptions as to what a given subset of students may find more appealing or motivating, even should it be based on research from other student subsets, the margin of error will be much higher than if a given subset of students themselves choose the gamified elements that motivate them the most. Through a dynamic approach, the experience a given set of students has with the gamified application will be different in each iteration of its implementation. Further, the differential in implementation is not arbitrarily decided. Rather, it is dynamically implemented based on the students themselves and will, by the given characteristics of both DG and CGD, maximize student motivation and engagement. In this sense, the application will customize itself without any assumptions on behalf of the researchers.

Along with the dynamic configuration advantages, DG and CGD also help keep code and applications relevant to changing demands. They keep the game from becoming stagnant and allow continual change to meet progressing technological sophistication. Because DG and CGD provide engaging, creative, interactive experiences, they are also useful in developing skill-sets to enable student success in modern software development professions.

Additionally, DG and CGD help alleviate cheating due to massive shifts in code between implementations. One issue faced when assigning coding exercises in DSA courses is the extensive and readily available DSA-type projects available online or from previous students. Using GD and CGD addresses this issue as each dynamic iteration of the game differs significantly, ensuring that copied code will not function from one iteration to the next.

D. Detriments of the New Abstract Gamification Classifications

While DG and CGD can provide a great deal of benefit, they can also create massive complexity in terms of actual execution. In order to effectively implement DG and CGD, a much more sophisticated, and therefore more complex, selection of software must be utilized. This complexity will inevitably lead to code deficiencies, flaws, and outright program corruption. When allowing students to participate to such an extent in the development of the framework and the implementation of the gamified application, researchers effectively lose many of the safeguards that are so favorable when creating more static gamification applications.

A secondary outcome of the complexity created by DG and CGD is the amount of work required for a gamified administrator to effectively implement the application. When allowing students to dive so deeply into the game that they can corrupt it, the administrator must play a more active role in fixing broken code and ensuring that the application functions to its full potential. For many educators, this effort can cause an inherently averse response to the actual use of such a solution.

VI. Future Work

As outlined above, there are many opportunities to not only learn about currently existing DSA gamification solutions, but also to explore new and previously unknown areas in the field. Through this study, we identified three main problem areas:

1) there are a limited, highly homogeneous number of DSA gamification applications,
2) DSA gamification requires more development and study,
3) there are multiple abstract gamification genres that have yet to be explored

It is the intent of the researchers of this paper to pursue to a greater extent issues 2 and 3. We intend to carry out a thorough study of Dynamic Gamification in DSA education, define and detail an actual dynamic implementation, observe its use first hand in a DSA course, study student outcomes in the use of dynamic gamification.

In the course of expanding this work, several research questions have yet to be addressed:

- Is the current definition of gamification adequate and are current gamification applications suited to best represent the spirit of gamification?
- Is the current use of gamification moving the discipline toward more efficient, functional applications?
- Can a general testing and evaluation methodology be developed to objectively quantify the efficacy and functionality of a given gamification application?
- Does the classification structure created by this study, apply to all CS education gamification applications?

The researchers of this paper intend to study the hypothesis that the classifications system created in this study will fit a broader scope for all CS education.

VII. Conclusions

It is the general conclusion that DSA gamification applications have, in a general sense, performed historically well. This performance seems to be due to the limited domain of possible solutions as well as the overall difficulty presented by DSA coursework gamification design. Because DSA coursework inherently requires the use of visual representations of complicated, step by step processes, gamification as a practice in DSA tends to fit well and create a beneficial set of outcomes.

This study defined a classification system for existing DSA gamification applications and discovered two abstract gamification genres that have yet to be instantiated. Through this classification of existing DSA gamification applications, this study determined that, though the applications that currently exist have performed well, the limited number of applications available for study indicate that DSA gamification requires more development and study. Further, in identifying new and unexplored genres, the undiscovered potential for efficiency and functionality of DSA gamification applications provides many opportunities for future research.

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