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Building a Local Curricular Diffusion Model based on a Gamified Homework Platform in First Year Engineering: A Case Study

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ABSTRACT

Implementation of educational innovations on a local scale requires consideration of a variety of different factors including stakeholders, curriculum design, classroom context, and culture. Although theories exist for dimensions of scale and diffusion of educational innovations across multiple institutions, they do not focus on the elements necessary to achieve a successful diffusion of a curricular innovation in a local context. This work leverages Actor Network Theory (ANT) and other theories on dimensions of scale to develop a framework for the local diffusion of a digital gamified homework platform called 3D GameLab. As a case study, we offer research findings around the key actors in the local curricula scale-up network and explore the relationships between these actors and how they work together to ensure an effective implementation. This model can be used as a guide for engineering education practitioners when seeking to expand the reach of their local educational innovations.

Key words: First-year Curriculum, Educational Software, Diffusion

INTRODUCTION

There are a variety of different models available to educators interested in scaling up or diffusing their educational innovations outside of their institutional context (Barab and Luehmann, 2003; Clark and Dede, 2009; Coburn, 2003; Stanford et al., 2017). However, there is a gap in the literature on how educators may seek to diffuse an educational innovation within their own institution. In the current work, we present a developed framework for the local curricular diffusion of the 3D GameLab platform created by the application of Actor Network Theory (ANT). 3D GameLab was developed to encourage students' motivation towards homework completion and provide students with choice in their homework selection. After two years of piloting the digital homework platform with two sections of students, the platform was scaled for use across 17 sections of a first-year engineering course.

The developed framework leverages Actor Network Theory (ANT) and builds upon existing theories relative to dimensions of scale and diffusion of educational innovations. As a case study, we offer research around the key actors in the local scale-up network - Designed Curriculum, Instructor Perceptions, Classroom Culture, and the Individual Student Experiences - along with the relationships between them as they relate to 3D GameLab. Our work provides important value to the engineering education community as it ties into the need for more research focused upon the adoption and implementation of evidence based teaching practices (NRC, 2012) and provides guidance for engineering educators that are seeking to expand the reach of their curricular development within their own institution.

In the sections that follow, we first present the conceptual framework for representing the various dimensions important for scalability. Afterwards, we discuss the developed framework for local curricular diffusion using an ANT Activity Diagram (AAD) model and highlight the key actors. Then we delineate results of applying the AAD framework to our particular case, 3D GameLab. Finally, we describe conclusions and implications for future research.

Dimensions of Scale Models

Coburn (2003) defines scale as encompassing four interrelated dimensions: depth, sustainability, spread, and shift. According to Coburn, ***depth*** refers to "deep and consequential change in classroom practice, altering teacher's beliefs, norms of social interaction, and pedagogical principles enacted in the curriculum"; ***sustainability*** "involves maintaining these changes over substantial periods of time"; ***spread*** is based on the "diffusion of innovation to large numbers of classrooms and schools"; and ***shift*** involves districts, schools, and teachers "assuming ownership of the innovation, deepening, sustaining, and spreading its impacts." (Coburn, 2003). Clark and Dede (2009) extend Coburn's framework to include ***evolution***, which is when adopters of an innovation "revise it and adapt it in such a way that it is influential in reshaping the thinking of its designers". From a design perspective, various types of activities can be used to achieve scale along each dimension as shown in Table 1.

Other frameworks for the concept of "scaling up" have also been developed. Barab and Luehmann (2003), describe the role of the teacher perceptions (of both the innovation and classroom culture), the designed curriculum, and classroom culture on the implemented experience of an educational innovation (see Figure 1). In a study by Leuhmann (2001), 30 secondary science teachers were asked to identify the factors most important to them when appraising and considering an innovation for adoption.

Table 1. Activities to achieve scale (Clark and Dede, 2009).

Depth	Sustainability	Spread	Shift	Evolution
Design-based research to understand and enhance causes of effectives	Robust design to enable adapting to inhospitable contexts	Modifying to retain effectiveness while reducing resources and expertise required	Moving beyond "brand" to support users as co-evaluators, co-designers, and co-scalers	Learning from users' adaptations to rethink the innovation's design model

The results showed that no single factor was identified by the majority of the participating teachers indicating a high degree of variability in the customization process. In fact, a cluster analysis of the identified factors revealed five diverse groups of teachers defined by their shared concerns: *subject-matter focused, scaffolded optimists, logistically focused, accountability focused, and pedagogically savvy* (Leuhmann, 2001). Research on teacher-controlled change has revealed that biography, experiences, personality, and context play a role in the change choices that individuals make (Richardson and Placier, 2001). Classroom culture may explain the largest portion of variance of the "implemented experience". Classroom culture can include available resources, classroom norms, external classroom pressures, the students, and the role of the teacher (i.e., pedagogical perspective, learning goals, interests, content expertise, school roles, self-efficacy, prior experiences). Classroom innovations, Barab and Luehmann argue, are thus "co-constructed and socially derived" (Barab and Luehmann, 2003).

Clark et al. (2006) further outline factors important in the effectiveness of scalability strategies, discussing concepts such as teacher preparation; degree of individualization and interaction; student academic achievement; and student engagement (Clark et al., 2006). Bringing a technology innovation to scale in education requires a design that is flexible enough to be used in a variety of contexts and robust enough to retain effectiveness in settings that lack conditions for success (Clark and Dede, 2009). Other articles focus on various aspects of teacher adoption through diffusion, as discussed in the subsequent section.

Diffusion of Educational Innovations

One method discussed in the literature for scaling-up educational innovations is propagation. Propagation can be defined as "adoption of an innovation by users beyond the original development

Teachers Perceptions + Designed Curriculum + Classroom Culture = Implemented Experience

Figure 1. Elements of the Implemented Classroom Experience (Barab and Luehmann, 2003).

team" (Stanford et al., 2017, p. 2). A recent model proposed by Khatri et al. (2016) for the successful propagation of educational innovations involves three key components: (1) development of the educational innovation interactively; (2) interactive dissemination of the educational innovation; and (3) supporting adopters with their use of the educational innovation. Khatri et al's model proposes, in part, that interaction with key stakeholders and potential future adopters during the early stages of the design process will yield a better overall final product. They further discuss the improvement of connective support mechanisms available to adopters, namely interactive dissemination strategies such as immersive workshops and personal communications.

In a study by Stanford et al. (2017) that examined the results of 71 NSF funded educational innovations based upon Khatri et al.'s model, it was found that many faculty don't actively consider propagation strategies as part of their development of educational innovations, leading to a smaller percentage of adoption of these innovations outside of their initial context (~20%). They also identified several critical factors for successful propagation of educational innovations, including the active identification of potential adopters and developing an understanding for different educational systems and how these systems could lead to barriers for implementation. Stanford's work supports earlier results by these researchers that demonstrated many faculty focus primarily on curriculum and pedagogy dissemination with the assumption that if the innovation is well tested and shown to be successful, individuals will naturally adopt it (Henderson, Finkelstein, and Beach, 2010).

To assist in translating the proposed model into practice (Henderson et al., 2015) have created a guide book for faculty with actionable items on how to propagate educational innovations. The strategy identifies two phases: (1) understanding the changes that are required for achieving a sustained adoption and (2) developing an action plan. According to (Henderson et al., 2015) in the first phase, faculty should be seeking to better define their educational innovation, what is involved in its use, and what the desired implementation of the innovation in the classroom should be. They should use the information obtained to help guide them in the identification of individuals who could be early adopters of the innovation. Once early adopters are identified, faculty should perform a needs analysis to better understand what these early adopters are seeking in an educational innovation and what barriers might exist within their educational system that could prevent the adoption of the educational innovation. In the second phase, faculty follow the strategies proposed within the model of Khatri et al. (2016) to ensure that the educational innovation is being developed in conjunction with discussions with early adopters. Following the proposed method helps to ensure that the innovation and any supporting materials address concerns and barriers that were identified in the first phase of the innovation's development (Henderson et al., 2015). To assist with the development process, faculty can use the "Designing for Sustained Adoption Assessment Instrument," which can help identify issues with the proposed faculty propagation process and select alternative methods that could lead to better outcomes (Stanford et al., 2017).

Actor-Network-Theory

One social learning theory that can be used to address the many stakeholders that influence the scale-up or diffusion of an educational innovation is Actor-Network-Theory (ANT). ANT was developed by Latour (2005), and can be considered more of a practice rather than a theory (Bleakely, 2012). ANT is considered to be a "process-oriented sociology that treats agents, organizations, and devices as interactive effects" (Law, 1992, pg. 389). ANT focuses on persons or objects (can be human or non-human) that may have a stake in the way that a system functions or operates. These actors exist within a network, the links of which are created by translations or meaningful connections between actors. Within the network itself, the actors should act as 'mediators' actively engaging in processes necessary in order to advance the network towards its main objective (Bleakely, 2012). ANT includes these key elements: semiotic relationality, heterogeneity, and materiality (Law, 2007). In other words, it consists of humans and non-humans that serve as actors, whose connections with one another can influence outcomes with each other. An additional feature of ANT includes that it captures the process and relationships between actors including mediating factors in these relationships such as power (Law, 2007). The benefit of ANT is that it encourages researchers to explore how social effects relate to the power, structure, and organization of a system. More specifically, it seeks to understand the causes and effects of interactions that occur between actors within the network (Law, 1992). ANT has been used in a variety of different fields including economics, education, gender, medicine, politics, and science (Kovshenin, 2000).

To better illustrate how ANT can be applied to a science and technology concept, we provide a brief summary of the work done by Williams-Jones and Graham (2003) on applying ANT to describe the process involved in development of genetic techniques. In their study, there were a number of human actors including patients and families, academic researchers, individuals at biotech and pharma companies, as well as individuals working within public health care services. However, they also had non-human actors that comprised their network including the genes under investigation, the tests performed on the genes, and patents already in place or current patent law that would affect the intellectual property associated with the genetic techniques. Each of these actors had the capacity to influence one or more other actors within the network, which could result in changes in the overall genetic technique development process. For instance, the academic researcher seeking to discover a new gene will be influenced by current patents in place and the patent law process as well as by the focus of current funding efforts within the public health care field. Similarly, the development of a new genetic test will be impacted by a patient's needs for the test, health care professionals that need to administer the test, and the researcher performing the development (Williams-Jones and Graham, 2003).

Recently, Payne (2017) developed a method called ANT Analysis Diagrams (AAD) that assists with the visualization of the components and connections existing within ANT. AADs provide a means to distinguish between different actors within the network separating out those that are considered fluid, immutable mobile (fixed) or "fire" (not always present / optional). A similar approach was taken for denoting the relationships between the actors within the network. As Payne (2017) describes, it is important in the overall construction of the AAD that the researchers make choices that lend to the accurate understanding of the network while still ensuring its coherence to others.

Proposed AAD Model for Curricular Diffusions

We applied an Actor Network Theory Analysis Diagram (AAD) to develop a relational model for curricular diffusion for 3D GameLab, a new, personalized digital homework platform. The visual model represents a socio-educational network of people, technologies, roles, perceptions, and curriculum that we believe are essential in the local diffusion of a game-based educational innovation. The model comprises actors/objects, their associated properties, and the relationships between them (see Figure 2).

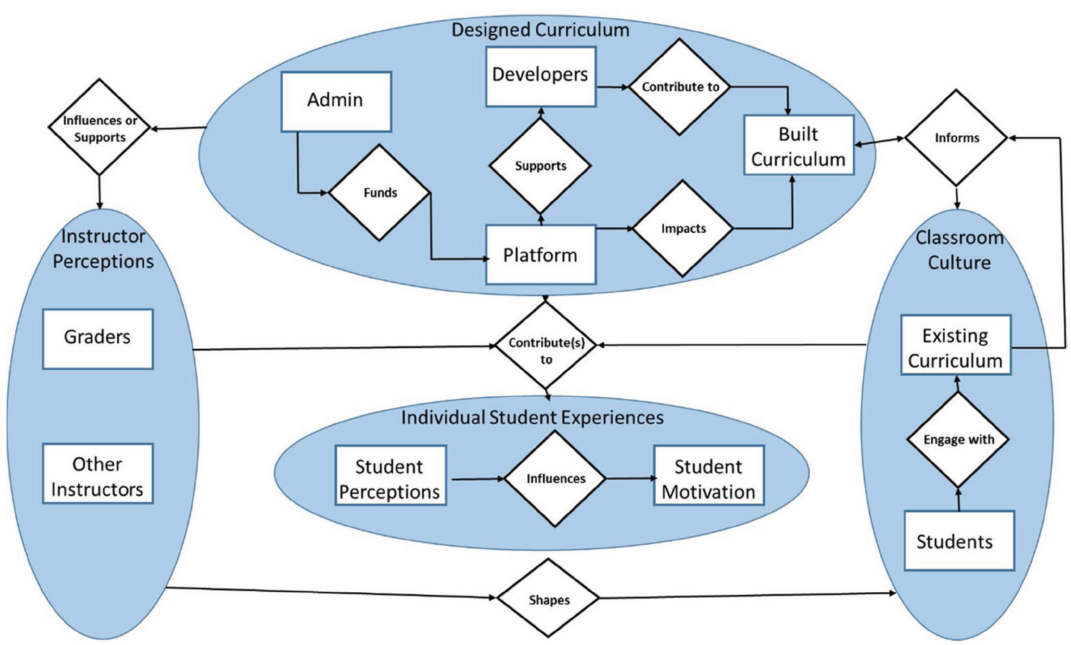

Figure 2. Actor Network Theory Analysis Diagram for Local Curricular Diffusion – 3D GameLab.

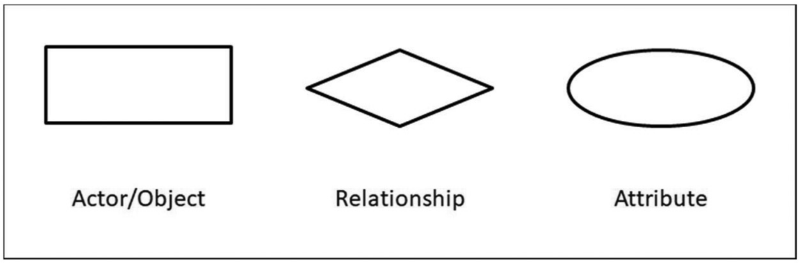

Figure 3. Actor Network Theory Analysis Diagram (AAD) Notation.

An AAD can be thought of as a variant of an entity-relationship diagram (ERD) used in standard databases design, using Actor Network Theory concepts. The notation used employs different shapes and styles. In general, solid lines are used for objects that are 'fluid' or subject to change, double lines are used for objects that are fixed or 'immutable', and dashed lines for objects which do not always exist and are regarded as optional. It is worth noting that most objects in Figure 2 were found to be best presented as 'fluid', as is typically the case when considering human or social elements (Payne, 2017).

The implemented experience framework developed by Barab and Luehmann (2003) was used to frame the overall structure of the AAD for GameLab - emphasizing the actors in regards to the designed curriculum, instructor perceptions, and classroom culture. Work by Khatri et al. (2016) was leveraged to determine directions of influence between actors in the network, namely the interactive nature of development of the GameLab curriculum, iterative dissemination of the innovation to multiple student groups, and the support of adopters through training and focus groups. Finally, the Dimensions of Scale model by Coburn (2003) was used to further identify important relationships and actor characteristics. Using a combination of scale and diffusion theories guided by our case study, a list of actors was identified (see Table 2). In the following section, we describe each area of the model in detail and how it was developed.

Building from the designed curriculum, there were three other elements of the local diffusion that became evident as necessary for a successful implemented experience. These elements were instructor perceptions, student individualized experiences, and classroom culture. Although in the work of Barab and Luehmann (2003), components such as student perceptions and motivation were grouped under classroom culture, it was found in our model that these components needed to be separated as they played a pivotal piece in how the other elements of the local diffusion model interacted. For instance, designed curriculum, instructor perceptions, and classroom culture all contributed to student perceptions of the educational innovation, which have been shown to

Table 2. Actors in Model for Curricular Diffusion.

Actor	Description
Designed Curriculum	
Platform	The technology supporting the innovation (i.e. GameLab)
Built Curriculum	Quests, benchmarks, badges, rewards, etc.
Developers	Responsible for built curriculum and scale-up (authors)
Administration	Department Head / Dean of College
Instructor Perceptions	
Other Instructors	Instructors (non-developers) implementing GameLab
Graders	Upperclassmen who grade student responses on GameLab • characterized by pedagogical perspectives and experience
Classroom Culture	
Students	First year participants on GameLab
Existing Curriculum	Established first year curriculum • characterized by norms and external pressures
Individual Student Experiences	
Student Perceptions	First year student perceptions of content, platform, etc.
Student Academic Motivation	First year student academic motivation to engage with and learn content through platform

influence directly student motivation as discussed by Jones (2018). It was also found that since student motivation was a construct that was being measured as a function of the implementation of the educational innovation, and thereby not directly available to instructors during their teaching of the course – it was more of a precursor to the built curriculum than it was to instructor perceptions.

The proposed model shown in Figure 2 helps to explain how local diffusion of an educational innovation takes place. Although it does not incorporate all of the elements of current scale-up and diffusion models, it does account for the key actors and relationships that occur when an educational innovation is locally diffused.

GAMELAB AS A CASE STUDY FOR LOCAL CURRICULAR DIFFUSION

This section will focus on demonstrating how Actor Network Theory (ANT) was used as a framework for modeling a local curricular diffusion by accounting for the key stakeholders that were part of the educational innovation diffusion. 3D GameLab, a personalized digital homework platform, was diffused locally from two sections of a first year engineering design course to 17 sections of the course at a single institution over a period of 3 years. The case study will be framed around key actors in the network including: designed curriculum, instructors, and classroom culture (students and graders on the platform) as highlighted in Figure 2.

Designed Curriculum

The first actor within our actor network theory is designed curriculum. Designed curriculum was found to be the starting point for the proposed model in Figure 2, as it was the foundation that the implemented experience was built upon. Having a stable curriculum that provides the intended course learning outcomes for students is critical before taking the steps to diffuse the educational innovation in a local context. Beyond the curriculum however, it is also necessary to get the appropriate administrative support and buy in from other key stakeholders involved in the implementation, as highlighted in Khatri et al's (2016) propagation model. Buy in can involve discussions with relevant administrators but also includes securing the appropriate resources and providing support for implementers. For instance, it would not have been possible to undertake the local diffusion of GameLab without administration support, as the administration enabled the spread of the innovation from two sections to the entire first year curriculum by providing resources for graders, training, and local support for the need to diffuse this innovation across the entire curriculum. As outlined in Coburn (2003), spread is a key characteristic of scale-up of an educational innovation. Likewise, the support of adopters is critical in diffusion of educational innovations (Khatri et al., 2016).

3D GameLab

3D GameLab is a personalized digital homework platform created by Haskell and Dawley for gamifying education (Deichler and Adams, 2013). The technology platform consists of a web portal that allows for curriculum designers to create content in the form of "quests" or individual homework assignments that can be provided to students in a class based setting. It also incorporates key features associated with a gamified learning environment (Kapp, 2012) such as profile cards for individual students, progress bars to demonstrate the level of attainment the student has reached both in the current level as well as the course overall, and continual accrual of experience points or "XP". In addition, the system has the capacity for inclusion of badges, achievements, and awards which can be used to enhance student motivation for achieving desired course objectives. The platform also operates on the premise of mastery learning in which individuals aren't penalized for submitting work that is incorrect and can re-submit a quest as many times as necessary until approval is obtained. Rapid feedback and no penalty for wrong submissions invokes the learning through failure approach commonly attributed to game-based learning (Whitton and Moseley, 2012). Figure 4 shows an example of the 3D GameLab interface that is hosted by Rezzly.

Developing the curricular content that would be used in 3D GameLab took place through an action research approach as described in Kulhanek, Butler, and Bodnar (2019). The action research cycle followed the method outlined by Kolk (2017) and included the following key steps: (1) defining goals for the platform development; (2) creating an action plan for reaching those goals;

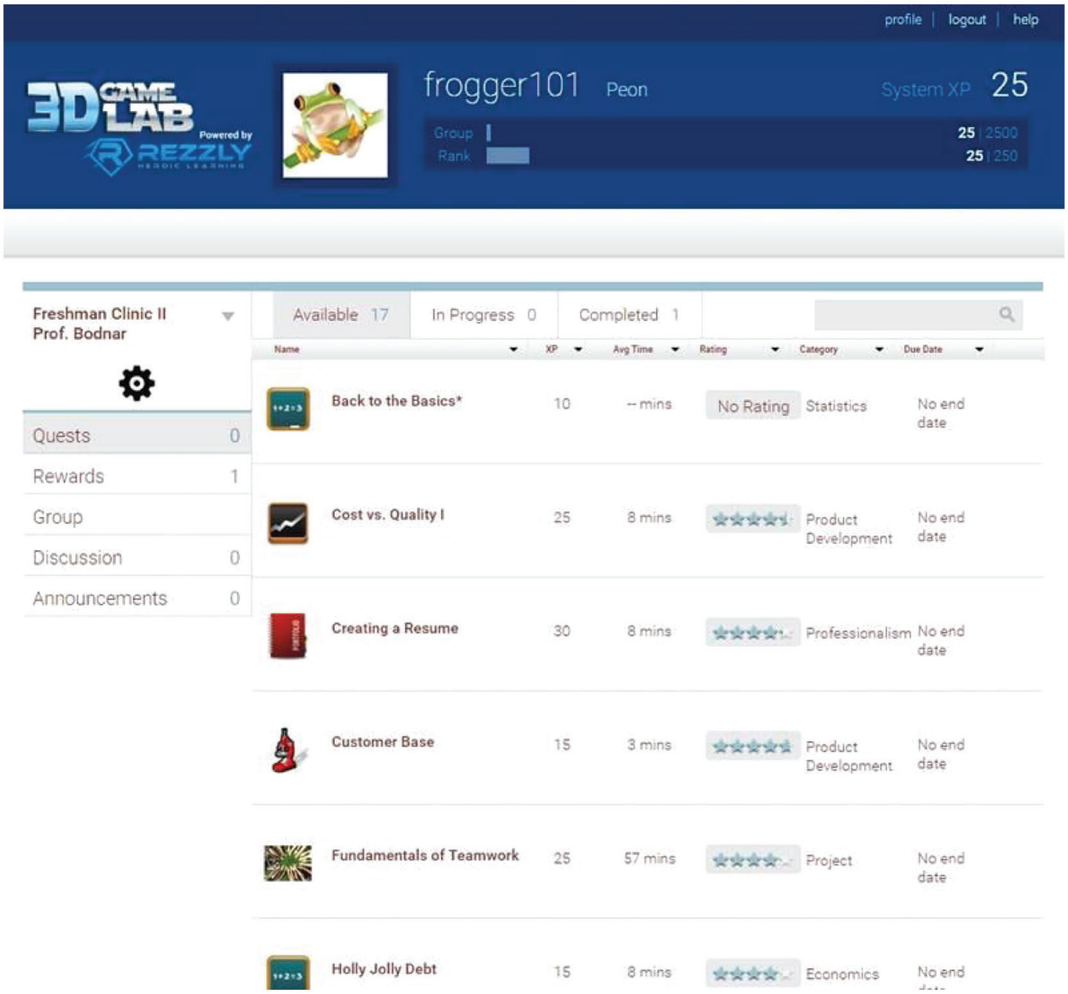

Figure 4. Student view of 3D GameLab Interface (Butler and Bodnar, 2017).

(3) collecting data about the platform's performance; (4) reviewing and analyzing the data collected from the platform implementation; and (5) adjusting the theory and goals based on outcomes and then moving forward with changes. The goals of the design of the gamified homework platform were to encourage student motivation towards homework completion and determine how students approached completing homework using the platform, given that they had more choice in activities and pathways that they could follow to attain a successful outcome.

The method used to investigate the impact of the curriculum (i.e., 3D GameLab) was to assess students' motivation within a classroom context via Brett Jones' MUSIC Model of Academic Motivation (Jones, 2009, 2015). Motivation in a broad sense is the extent to which one intends to engage in an activity. Engagement is important because it directly affects outcomes such as learning and performance. The MUSIC model includes five subscales: Empowerment, Usefulness, Success, Interest, and Caring. **Empowerment** relates to whether students feel they have choice within a classroom environment; **Usefulness** describes whether the students believe that the course material is important to their learning and future goals (Jones, 2009, 2015); **Success** pertains to whether students believe that they can be successful in the course if they complete the necessary activities and put in the required amount of effort (Jones 2009, 2015); **Interest** focuses on whether students find the content useful in the class they are taking (situational) and relates back to topics of interests for a sustained period of time (individual); and **Caring** refers to the relationship that exists between the instructor and the students within the classroom environment (Jones 2009, 2015). Measurement of student academic motivation is done with a 26-item inventory that allows students to rate statements on a 6-point Likert agreement scale ranging from 1 - strongly disagree to 6 - strongly agree. The coding for the MUSIC model inventory is available in the user guide developed by Brett Jones (Jones, 2015). Students' MUSIC perceptions are important because research has shown that these perceptions are related to motivation, engagement, and consequently, outcomes (see Figure 5) (Jones, 2018).

The design of content for the 3D GameLab platform included generation of 80 unique quests for students to undertake, each focused on different course learning topic areas. The final platform also had a series of badges that encouraged student pursuit of both breadth across all of the course

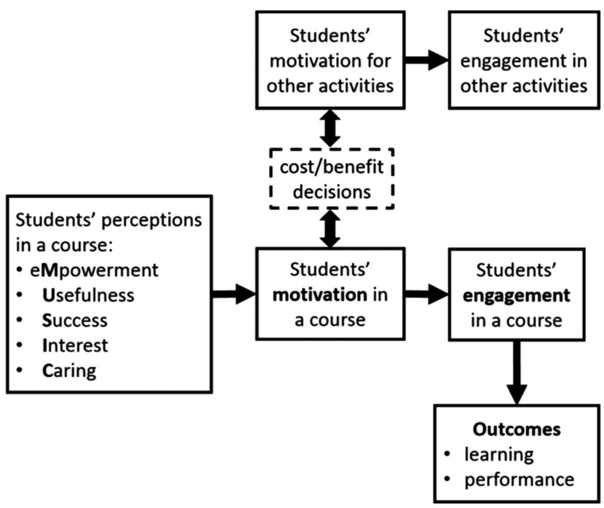

Figure 5. The relationship between students' MUSIC perceptions and their motivation, engagement, and outcomes. From "Motivating Students by Design: Practical Strategies for Professors, by B.D. Jones, 2018, p.10. Copyright 2018 by Brett D. Jones. Adapted with permission.

topic areas as well as depth in particular course topic areas. Finally, achievements and awards were available to enable students to be rewarded for putting in extra effort or moving ahead of assigned course benchmarks (Gulotta et al., 2016).

Prior to the platform being ready for local curricular diffusion, the curriculum design went through two cycles of action research. The first cycle showed that students had reasonable motivation in each of the five areas of the MUSIC model with a mean score across 21 students in one section of the first year engineering design course of 4.30 for empowerment, 3.80 for usefulness, 3.99 for success, 3.75 for interest, and 4.73 for caring where on the 6-point Likert scale, described above, a 3 represented somewhat disagree, a 4 represented somewhat agree, and a 5 represented agree. The results from the student focus group demonstrated that students felt improvements could be made between the linkages in the platform and the course curricular content. They also mentioned that the point structure for the quests on the platform should be improved as almost all of the quests had the same point value regardless of the amount of time and effort that was necessary to complete the task. Students did mention that they felt GameLab was a useful platform as it provided them the opportunity to have choice in their homework (Butler and Bodnar, 2017).

During the second cycle of action research, significant changes were made to the 3D GameLab platform to more closely align the quest content with the exact course topic areas, including development of additional quests that assisted with student professional development such as “Creating a Resume” and “Writing a Lab Report”, and changes to platform point structure. The point structure of the platform was overhauled to ensure that quests, which required significant effort had higher point values (in the range of 30-40 XP), whereas quests that were quick and easy to accomplish had lower point values (in the range of 10-25 XP). The results obtained from the MUSIC model for Spring 2017 showed improvements across all of the categories resulting in mean scores of 5.08 for empowerment, 4.87 for usefulness, 5.04 for success, 4.58 for interest, and 5.63 for caring in a single course section with 19 student responses. The focus group results were also more positive in the second implementation with students remarking that the quests provided a good variety of choices and enabled students’ choice over what activities they would like to complete (Kulhanek, Butler, and Bodnar, 2019). Results for only a single section of the implementation during the curriculum design phase are included in our current study as the instructor of the course can influence the results presented. Both sets of results presented here are from the same course instructor.

After the last round of results it was believed that the designed curriculum for 3D GameLab was ready for use at a larger scale and as such the initial plans for the local curricular diffusion of GameLab were established. In the Fall of 2017, slight modifications were made to the platform to respond to the student feedback from the prior semester but overall the platform was only polished and reviewed to ensure that it was ready for implementation across 17 sections of the course. The intention of the curriculum designers for the local curricular diffusion of GameLab was to enable all of the first year engineering design course students to have choice in their homework activities. The ability for students to select quests that best align with their interests is akin to providing personalized learning opportunities to the students.

As the developers didn't have input on the design of the platform, they were forced to work within the constraints of what the platform was capable of and design a built curriculum that leveraged the strengths of the platform while minimizing any elements that were lacking. Figure 2 showcases how the platform supports the developers who then contribute to the built curriculum. As recently discussed, the designed curriculum went through an iterative process of development prior to its local diffusion where feedback was sought from early adopters, which may have led to its success during the local diffusion process. Henderson and colleagues have shown through their "Increase the Impact" work how critical it is to understand the needs of early adopters to enable a successful diffusion of innovation (Henderson et al., 2015). In the GameLab case study, during each of its initial implementations, 3D GameLab was implemented in two sections of the first year engineering course with one section being taught by a curriculum developer and the other section being taught by a potential early adopter. Through an action research method of development it was possible to learn from earlier implementations that could help guide the innovation design model (Clark and Dede, 2009) as well as better understand the needs of early adopters during the curriculum design process as was shown to be important by Khatri et al. (2016).

Verification of Stability of Designed Curriculum

The MUSIC model survey was administered to students in two sections of the first-year engineering design course who participated in 3D GameLab during in Spring of 2017. The survey was administered again to students across 17 sections of the same course in Spring 2018. First, the scores for each subscale of the MUSIC model were compared across two sections (in 2017 and 2018, respectively) led by the same instructor. To evaluate the differences in the scores we ran Mann-Whitney's U tests, which are non-parametric tests that determine whether two independent samples from a population have the same distribution (i.e., have the same median). As a result, the medians for each subscale for the 2017 and 2018 cohort can be seen in Table 3. We found no significant differences between the two sections on any of the MUSIC model subscales (Empowerment – $U=106$, $Z = -1.29$, $p=0.20$, $r=0.22$; Usefulness – $U=124$, $Z=-0.65$, $p=0.53$, $r=0.11$; Success – $U=89$, $Z=-1.88$, $p=0.06$, $r=0.32$; Interest – $U=103$, $Z=-1.38$, $p=0.17$, $r=0.24$; Caring – $U=108.5$, $Z=-1.21$, $p=0.23$, $r=0.21$). Although minor differences were observed, these results suggest that given the same instructor, the effect of the curriculum on student academic motivation remains relatively stable.

Table 3. Results of Mann Whitney U Tests on Median Scores of MUSIC model.

Cohort	n	Empowerment	Usefulness	Success	Interest	Caring
2017	19	5.20	4.80	5.00	4.67	5.67
2018	15	5.00	5.00	4.75	4.17	5.50
p-value		0.20	0.53	0.06	0.17	0.23
*r**		0.22	0.11	0.32	0.24	0.21

*; 0.1-0.3 (small), 0.3-0.5 (medium), > 0.5 (large)

Administrative Support

Designed curriculum, such as the 3D GameLab platform, can't be locally diffused without the support and assistance of the college administration. In preparation for the local diffusion of 3D GameLab, the curriculum designers met with the Department Head in charge of the first year engineering design course to ascertain support for the broader implementation of GameLab and respond to any questions and concerns that were raised. The conversation with the Department Head allowed for involvement of the stakeholders in the diffusion process and identification of barriers that needed to be overcome before the implementation of the platform across all sections as discussed in Khatri et al. (2016). The meeting also enabled the determination of resources that were available for the local diffusion including financial resources for grader support on the platform and administrative backing for the use of the platform, both of which could be beneficial when meeting with course instructors that would now have GameLab as part of their course structure, as highlighted in the relationship outlined in Figure 2.

The implementation across the 17 sections had students broken down into 5 distinct platform segments, corresponding to their assigned lab time for an average of approximately 60 students per platform, with 4 to 5 graders assigned per platform. To ensure that the platform would be properly managed when implemented, there were individuals assigned as the point of contact for each platform segment that would ensure grading was being done in a timely manner and follow up with any graders that were not completing their assigned duties. The point of contact individuals consisted of two upper level undergraduate students and one master's student who had worked on the development of the 3D GameLab platform and had previous grading experience with the platform, as well as the two faculty members involved in the curriculum design.

To provide the necessary support structure to assist with a successful implementation of the 3D GameLab platform, the curriculum designers hosted two workshops prior to the start of the implementation. The first workshop was with the upper level undergraduate graders who would be working on the platform, discussed in more detail under instructor perceptions below. These upper level undergraduate graders were competitively selected for the grader positions based on applications that they had submitted late in the fall semester. The graders represented a mixture of students from both junior and senior year, diverse genders, and a mixture of engineering majors. Some of the upper level undergraduate graders had been students in the class when 3D GameLab was first implemented in Spring 2016. The workshop with the graders covered the basics of the system, discussed how the grading process would operate, and provided an opportunity for each of the graders to practice giving feedback in the GameLab online environment. The discussion also covered what distinguished good and bad feedback and how to ensure that grading was done consistently when working on the platform. The workshop ended with students ranking their preferences in terms of course topic areas and schedule availability. Understanding graders' personal interests and time commitments allowed the curriculum designers to assign them to a platform segment that would work with their other commitments and emphasize their own personal interests on the platform.

The second workshop that was held prior to the implementation of 3D GameLab was a short session with instructors for the first year engineering design course. The workshop introduced the instructors to the system, provided them an opportunity to create their own accounts on the system, and gave them a forum for asking any questions that they may have about the platform and the process for implementation. The instructor workshop was held shortly before the start of the semester which may have limited the ability for instructors to feel that they had buy-in with regards to the platform and how it would be implemented.

Instructor Perceptions

The next actor in our actor network theory model consisted of instructor perceptions which was broken down into other instructors and graders. Instructors are essential to the success of local diffusion of educational innovations since they are the point of direct contact with the students. Instructors are continually remaking and contextualizing educational innovations in terms of their local context. Their perceptions of an educational innovation, as well as the culture they have contributed to defining for the classroom can influence the implemented experience.

To understand instructor perceptions of 3D GameLab, a focus group of instructors who implemented 3D GameLab in the Spring 2018 semester (n=7) provided feedback about their perceptions of the platform and its implementation inside the classroom. Instructors responded positively about the content on the platform, the personalized nature of the feedback, and time management practice via periodic deadlines, but emphasized "poor execution" and frustrated students. The feedback obtained was due to a variety of factors, including lack of clarity in quest expectations, lack of guidance when quests were returned by the graders, and inconsistency in grading from one platform to another.

The instructors in the focus group also discussed the integration (or lack thereof) of 3D GameLab into the curriculum. Some instructors admitted they barely mentioned the platform, while others discussed the disconnect between the traditional homework in the course and the content and structure of 3D GameLab. There was some disagreement on *how* 3D GameLab could be better integrated (i.e., open-ended exploration vs structured more as traditional homework). One area that all instructors agreed on was the desire for more access and control over the platform. Instructors reported not being able to help their students with quests due to lack of familiarity and connections to current course content. The feedback obtained could be related to the lack of instructor "buy-in" described above. It also could be related to the instructor workshop being held so close in timing to the start of the semester, which didn't provide instructors with sufficient time to familiarize themselves with the system prior to it being introduced to their students.

Instructors outlined in their feedback how they could see value in the system through their understanding of the need for time management and personalized feedback, which would be related to their experiences with instruction in the classroom. Likewise, their comments on whether the system should be used as a more traditional homework tool or open exploratory system, would have been guided by their pedagogical perspectives. These attribute observations were also supported by the work performed by Barab and Luehmann (2003). Student perceptions guided the instructors' perceptions of the implemented experience as their perceptions was conveyed back to the instructors during their time in the classroom environment. Figure 2 captures the relationship between these two elements by connecting individual student experiences to instructor perceptions.

Impact of Instructor Perceptions on Academic Student Motivation

We have already seen that the MUSIC model scores were consistent from one section to another with the same instructor. So what is the impact of the instructor on students' academic motivation? To investigate the relationship, non-parametric approaches were used to test whether there is an instructor effect on student academic motivation. Because our dataset violated some of the assumptions of multivariate analysis of variance (homogeneity of covariance matrices and multivariate normality for example), we decided to run two non-parametric tests: the Kruskal-Wallis H Test and Non-Parametric Inferences for Multivariate Data explicated through the R package npmv (Ellis et al., 2017). The Kruskal-Wallis H test (i.e., one-way ANOVA on ranks) is a rank-based test that can be used to determine if statistically significant differences exist between two or more groups on a continuous response variable. It is considered a generalization of the Mann-Whitney U test to allow comparisons between more than two independent groups. Nonparametric multivariate models test the following statistical hypothesis using sum of squares and cross-products based on ranks - "Do the treatments/groups have the same effect on the response?" To test the proposed overall hypothesis on multivariate distributions, rank-based test statistics of ANOVA type, Wilk's Lambda type, Lawley Hotelling type, and Batlett Nanda Pillai type are constructed. Details regarding these test statistics and underlying theory can be found in Bathke et al. (2008), Liu et al. (2011), and Ellis et al. (2017).

To explore instructor effect on student academic motivation, the MUSIC model survey scores were analyzed across all 17 sections of the first-year engineering design course, although only 13 sections received responses (n=191). The MUSIC model subscale scores were predicted by instructor number (treated categorically). The instructor variable allows each section to have its own mean and standard deviation. The instructor variable is therefore an amalgamation of all the characteristics that make each instructor different. Thus, no attempt was made to explain what makes instructors different; they were simply allowed to vary. If the instructor variable has an effect, it means that characteristics of the instructors effects student academic motivation. Boxplots of the MUSIC model scores for each section are shown in Figures 6 - 10. The ID variable represents instructor sections of the first-year engineering design course.

The results of five Kruskal-Wallis H Tests are described in Table 4. The results indicate that instructors have a significant effect across all five subscales of the MUSIC model. The results of the non-parametric models using F-approximations for ANOVA type, Wilk's Lambda type, Lawley Hotelling type, and Bartlett Nanda Pillai Trace test statistics comparing the multivariate distributions of the MUSIC model for the different instructors are described in Table 5. It is clear from both non-parametric approaches that a significant instructor effect exists when analyzing student academic motivation, which reinforces the notion that instructor perceptions are a critical element of the implemented experience for 3D GameLab.

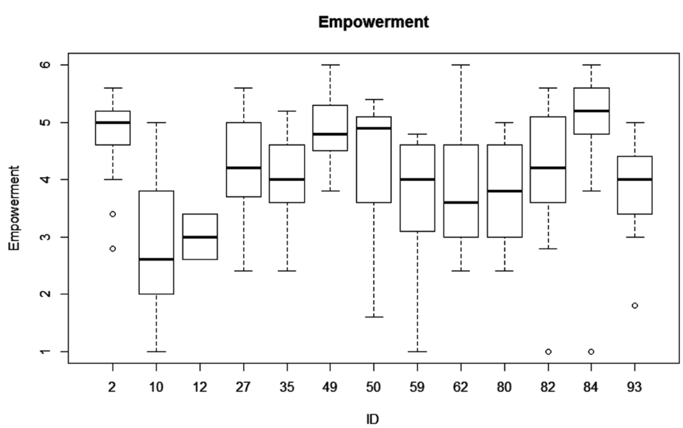

Figure 6. Boxplots of Empowerment Scores across Class Sections.

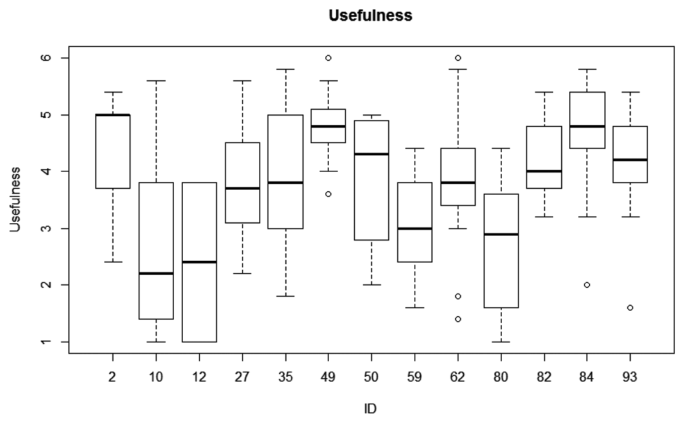

Figure 7. Boxplots of Usefulness Scores across Class Sections.

Feedback from the student focus groups showed that instructor perceptions were instrumental in shaping the classroom environment and culture that students experienced and thus contributed to their personal perception of the innovation. This observation is tied to the role that instructor perception serves in establishing the norms of the classroom environment. Students were also subject to external pressures that would have impacted their classroom environment due to deadlines for other assignments within the first year course, as well as work in their other assigned courses. Many of the first year students also work part-time to help support their college education, which would impact the amount of time that they would have available to engage with the platform and benefit from the designed curriculum.

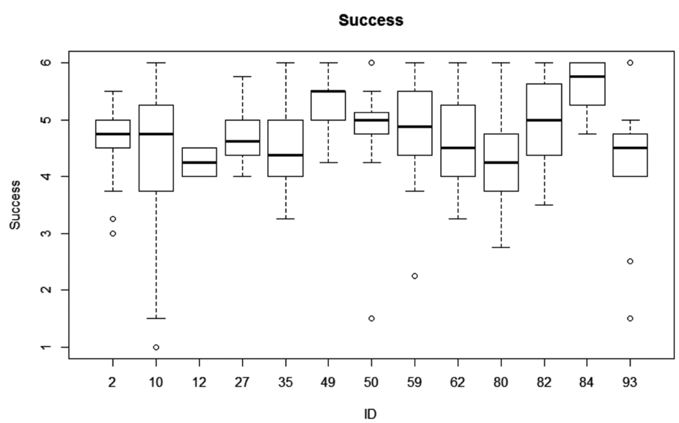

Figure 8. Boxplots of Success Scores across Class Sections.

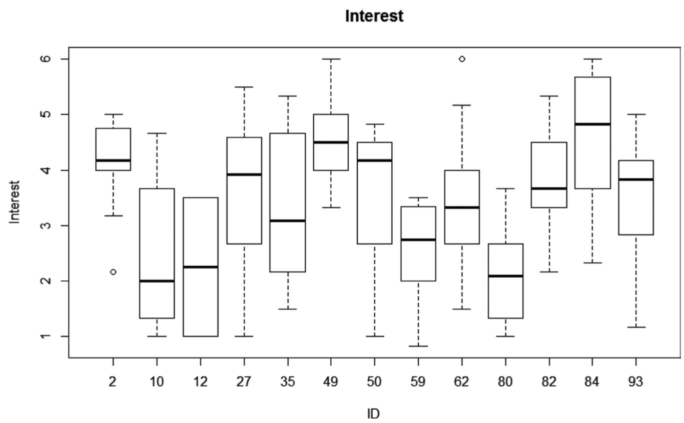

Figure 9. Boxplots of Interest Scores across Class Sections.

Grader perspectives

The other element that shaped instructor perspectives of the implementation was the perspectives of the graders that were employed to assist with the system. Unfortunately, only 1 of the 19 upper level undergraduate graders selected to participate in the focus group that was run to get their feedback. For this reason, the themes discussed are limited to a single student's perspective. Although only a single grader participated in the discussion, we believe that the underlying themes identified are representative of a larger student grader appreciation for the platform. The five junior level undergraduate graders that served on the implementation described in our work have continued to serve as graders throughout this past year demonstrating their continued interest in

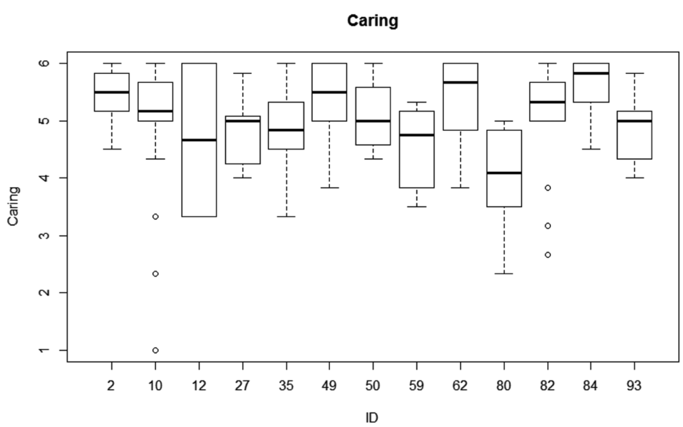

Figure 10. Boxplots of Caring Scores across Class Sections.

Table 4. Results of Kruskal-Wallis H Tests for Instructor Effect on Academic Motivation.

	Empowerment	Usefulness	Success	Interest	Caring
χ^2	58.55	61.76	46.27	71.30	51.26
df	12	12	12	12	12
Asymptotic p-value	<0.001	<0.001	<0.001	<0.001	<0.001

providing feedback to students through the GameLab platform. Out of the five original junior level undergraduate graders, only two of these graders had prior experience with 3D GameLab through their own coursework, demonstrating that both students having familiarity and those without familiarity with the platform find the grading process beneficial to their own professional development.

The grader participating in the focus group felt that there was a lot of benefit that could be obtained from the use of 3D GameLab as it provided the students a means to diversify their learning while building up skill sets in different areas. They also felt that there could be a lot of room for students to dislike the platform because it is a separate system from what is used within the classroom environment, and as such the students may see it as an add-on that does not directly apply to the goals of the course. The grader was a bit discouraged by the amount of effort that some students placed in their submissions. They felt that the students should take their submissions seriously and realize that their behavior on the system is a reflection of their professional conduct. The grader did their best to always provide prompt and helpful feedback to students that would encourage them to put in not only the work necessary but to strive to exceed these goals. However, the individual found it difficult at times to provide feedback when the submission was lacking in its initial form. Overall, the grader found that working on the GameLab platform was a beneficial experience and would serve in that capacity again. Based on their experience, they came up with similar suggestions to the students for improvement such as improving the transparency in the system and making the solution manual more explicit, which would respond to students' concerns about inconsistency in grading between different graders.

Table 5. Results of Non-Parametric Multivariate Models.

Non-parametric multivariate tests	Test Statistic	Df1	Df2	p-value
ANOVA type	3.26	21.68	165.29	<0.001
Wilks Lambda	3.34	60.00	818.55	<0.001
Lawley Hotelling	3.56	60.00	581.40	<0.001
Bartlett Nanda Pillai	3.10	62.13	916.80	<0.001

It was observed through the feedback obtained in the focus group performed with the grader that experience and pedagogical perspective were attributes that highly influenced their perception of the platform. For instance, the grader participating in the focus group had prior experience as a student using the 3D GameLab platform during its first implementation in the first year course. The grader's experience and knowledge of the platform as well as reflections on their own personal experience colored the way that they felt about the platform and its utility as an educational innovation. The grader's perspective of the aforementioned elements would have shaped the classroom culture that was created through the feedback they provided to students on the platform (Figure 2).

Classroom Culture

The final actor in our actor network theory model is classroom culture. Classroom culture was found to be centered on the students and how they were engaging with existing curriculum that was further reinforced through the addition of the 3D GameLab platform (see Figure 2).

Student Perceptions

To further explore student academic motivation, the MUSIC model survey was administered to 17 sections of the first-year design course who participated in 3D GameLab in Spring 2018. Out of 294 students, 191 responded (65% response rate). We first compared the MUSIC model scores from the students from 2017 (n=34) to the scores from the students from 2018 (n=191). Out of the 17 sections in 2018, we only included data from sections where 30% or more of the students responded to the MUSIC model survey. Further, we removed the data from two sections that had particularly negative experiences with 3D GameLab and were treated as outliers. The two sections that had negative experiences with 3D GameLab appeared to be as a result of miscommunication of the expectations associated with the homework platform which resulted in significant student resistance towards its implementation. Removing these data sets led to a final sample size for the 2018 cohort of n=150. Independent sample t-tests were conducted for each MUSIC model subscale. The means, standard deviations, p-values, and effect sizes (Hedge's G) are reported in Table 6. We found statistically

Table 6. MUSIC model score comparison for 2017 and 2018 student cohorts.

Mean *(SD)*	n	Empowerment	Usefulness	Success	Interest	Caring
2017	34	5.05 *(0.75)*	4.62 *(0.96)*	5.14 *(0.78)*	4.43 *(0.88)*	5.47 *(0.82)*
2018	150	4.31 *(1.06)*	4.11 *(1.11)*	4.83 *(0.87)*	3.80 *(1.19)*	5.13 *(0.72)*
p-value		<0.001	0.009	0.05	0.001	0.04
Hedge's G		0.73	0.47	0.36	0.55	0.46

significant decreases across all subscales from 2017 to 2018 and medium effect sizes in the Empowerment and Interest subscales. These results suggest that the effectiveness of GameLab was more limited when the platform was scaled up from 2 sections to 17 sections, especially in regards to their ability to make decisions about their learning and interest in the content and instructional activities. One reason why this result may have occurred includes the implementation of an "Introductory" badge into the platform that forced students to complete two quests in each of the course topic areas before being able to advance and make their own personal choices of quests. The Introductory badge was added in Spring 2018 to ensure that students across all of the 17 sections were meeting the minimum learning objectives of the course as part of their homework completion. The only means necessary for making sure that students could meet the minimum learning objectives requirement was to scaffold completion of the Introductory badge as a prerequisite for attaining higher level quests, which would make students feel more confined in the choice they were given within the system particularly in the initial phases of their interaction with the platform.

Apart from quantitative analysis of student perspectives on the implementation of 3D GameLab across all of the sections of the freshman engineering design course, the researchers felt it was important to also get more targeted student feedback on the platform through focus groups. At the end of the spring 2018 semester, a total of 6 focus groups, ranging in size from 1 student to 24 students, were run with 55 total students across the different sections of the freshman engineering design course. Each focus group was guided with a set of questions framed around academic motivation from Butler and Bodnar (2017) as shown below:

- Were these quests beneficial to you?
- How do you think you performed on these homework assignments? Were they too challenging? Too simple?
- Could these assignments be changed to make them more enjoyable, interesting or useful? How?
- Did you choose quests based off of rewards or personal interest? Or another reason?
- Which quests did you find most enjoyable? Least enjoyable?
- When did you find time to accomplish these quests? Before class? After class? Or another time during the week?
- Was it complicated or easy to remember to accomplish the quests? How often did your instructor remind you to do them?
- Did you feel as if your class time had an impact on your motivation to accomplish these quests?
- How much control did you feel you had over the quests?
- Do you feel as if the comments provided on quests have a positive, negative or neutral connotation on your work? Why?
- Additional Feedback

There were several overarching themes that arose from these discussions. First, the students highlighted a lot of the benefits that were associated with the system. For instance, they felt that the platform did provide them with choice and freedom in selecting the quests that they wanted to do, although the amount of freedom wasn't necessarily as much as they would have desired. Students liked that the platform was a means for reinforcing material covered in class and that the quests asked for them to apply the content versus just re-stating material that had already been covered. They found that the system was very beneficial in allowing them to develop time management skills. Unlike many homework systems, 3D GameLab was implemented with an end of semester deadline and monthly benchmarks to allow students to stay on track towards attaining their end goal. For many of these students, who were used to weekly homework from high school, the new approach to homework was a significant change and forced them to plan out how they would reach the course targets. The other aspect that students found very encouraging was the personalized feedback that was provided to them on the platform. They felt that the feedback was always neutral to positive and they never felt as if the graders were discouraging them from trying again.

Despite all of the positive aspects about the platform highlighted in these focus groups, the students also felt there were elements of the platform that could be improved upon or changed to provide them with a better homework experience. One example is the design of the quests which didn't include the information necessary to teach them the course topic. These quests referred students to the relevant topic in their assigned course textbook, and required that they apply the topic in a new application. Students felt as if more resources could be built into the quests to avoid them having to reference their class textbook. In doing so, they could have been more efficient in completing the quests assigned. They did feel that some of the quests were repetitive with respect to the material that was covered in class. As the platform was designed as homework that would reinforce course content, it is quite possible that students would have seem similar styles of problems that were embedded within the class material itself.

In contrast to the students that highlighted the benefits of the system providing a means to develop time management skills, some students felt that it was difficult to budget their time, and that the longer deadlines made it easy to procrastinate on assignments and then fall behind. Students commented that getting used to the mastery learning approach used with the platform was also part of the learning curve. Previously, students had worked on homework where they submitted the assignment and it was graded, and then they didn't have to do any further work. With the GameLab platform they were getting assignments returned to them, sometimes multiple times, which meant that the homework would take longer than they had budgeted for in the past. Finally, students commented on grading inconsistencies on the platform. As the GameLab platform was running across 17 sections of the course, there were 19 upper level undergraduate graders, one master's student as well as two faculty members that were responsible for grading quests on the platform. The implementation across the 17 sections had students broken down into 5 distinct platform segments, corresponding to their assigned lab time, with 4 to 5 graders assigned per platform. Although the graders on a platform were responsible for grading all the quests within specific assigned course topic areas, the students noticed inconsistencies between graders assigned to these course topic areas on the different platform segments.

The students' final takeaways were that the system could have merit and be beneficial for their learning process if more transparency was used and they had a means of better understanding how they could move through the system. The obtained student feedback relates back to the scores that were obtained during the MUSIC model analysis which showed decreases in empowerment once the platform was scaled across all the sections of the course. Although students were aware of the amount of experience point (XP) that they needed to attain by the end of the semester, they weren't always aware of what types of quests would be available at each rank in the system, since the quests were scaffolded based on rank and course content. Finally, students suggested that the graders be more direct in providing feedback so that the students could easily identify their errors, correct for them, and then get approval hence limiting the submission/resubmission cycle.

IMPLICATIONS AND CONCLUSIONS

The work conducted as part of this study has important implications for research and educational practice for local curricular diffusion of educational innovations. We offer a case study on the application of a contextually relevant framework, using Actor Network Theory, on the implementation of 3D GameLab across an entire first-year engineering student cohort (~300 students) that researchers and faculty can use as a guide in the design and evaluation of scalable classroom practice. The AAD framework can be used in the diffusion of other educational innovations because it focuses on an engineering department's effort to scale a gamified, learning experience without being overly specific about the technological implementation. The three primary areas of the model and the relationships between agents can be generalized to any educational innovation, with a particular focus on local efforts to scale educational practice. In 2012, the National Research Council (NRC) produced *Discipline-Based Education Research (DBER): Understanding and Improving Learning in Undergraduate Science and Engineering* (NRC, 2012), which contains a volume of insights and recommendations. Among its many recommendations included areas of inquiry related to the need for research on propagation or diffusion of engineering education research into practice; namely the extent to which engineering faculty adopt evidence-based teaching practices. The AAD model, as showcased through the GameLab case study, contributes to the growing body of research by providing an empirically-driven framework for which engineering education scholars may more rigorously study the phenomenon of local educational diffusion.

We suggest educators and researchers consider each area of local curricular diffusion (Designed Curriculum, Instructor Perceptions, and Classroom Culture) presented in the AAD, individually as well as the relationship each has with the others, when determining strategies for scaling local educational innovations. For example, educational researchers could investigate the relationship between the built and existing curriculum, with a focus on the nature of student engagement. Or how instructor perceptions and activity within the innovation shape classroom culture (and the aforementioned engagement). It is important that educators investigate not only the primary relationships present in the implemented experience, but the relationships present in each area separately. For example, educators should understand how technology supports the developers and the built curriculum. As engineering educators continue to create more innovative teaching practices and curricula, the AAD model can be used to reflect the realities and challenges associated with scaling innovations in a local context. Further, educators can evaluate the effectiveness of their current curricular diffusion efforts on measures related to student engagement and motivation, in addition to mapping their efforts to the AAD model to identify what areas they are not currently providing or need to be more directly addressed.

We developed the documented research study and framework to better understand the practices and standards for curricula diffusions of educational innovations in a local context. We intended to combine theory related to dimensions of scale (Coburn, 2003; Clark and Dede, 2009; Barab and Luehmann, 2003), diffusions of educational innovations (Henderson, Finkelstein, and Beach, 2010; Stanford et al., 2016), and actor network theory (ANT) (Latour, 2005; Bleakely, 2012; Payne, 2017) with a case study of local educational innovation propagation efforts via 3D GameLab. Bringing an innovation to scale across sections of a course, across departments, or even at the college level requires a process and design that is flexible enough to be used in a variety of contexts and robust enough to retain effectiveness across particularly challenging settings. The GameLab case study illustrates that designing and diffusing an innovation is a multi-stage process, requiring interactive development among co-designers and instructors; iterative dissemination across multiple student cohorts and contexts; and extensive support of adopters. Further, the AAD highlights building from the designed curriculum, the importance of instructor perceptions, the cultivation of a supportive and engaged classroom culture, and a clear understanding of how all of those factors contribute to the individualized student experience, especially in regards to student academic motivation. The elements of the AAD for local curricular diffusion will actuate differently across educational contexts. However, we are confident that the AAD effectively captures the primary areas for local curricular diffusion in a way that is useful for both research and educational practice. The AAD and the resulting findings will facilitate future work towards the adoption of educational practices in a local context and the effectiveness of those practices therein. In the near future, we are planning to revise our implementation of 3D GameLab across the first-year engineering experience using the AAD as a guide to ensure better student engagement. Further research will be conducted on each of the actors identified to better understand their relationships and develop best practices for scaling local curricular innovations.

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