An Epistemic Network Analysis of STEM Identity Exploration in Virtual Learning Environments

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Abstract: This paper reports group findings from three sessions of *Virtual City Planning*, a play-based course that supported the exploration of environmental science identities mediated by a virtual learning environment (*Philadelphia Land Science*), and supportive classroom activities. The Projective Reflection theoretical framework structured assessment of virtual and classroom data for 54 middle schoolers in a local science museum. Epistemic Network Analysis (ENA) was used to visualize different processes of identity exploration enacted by each session. Epistemic networks of class data by time period illustrated similar trajectories of identity exploration across sessions as an increase in personal interest and valuing of the domain over time, while paired-sample t-tests found chronological differences to be statistically significant across all sessions. Results illustrate ways in which virtual learning environments can support identity exploration and the potential future acquisition of science careers. The utility of ENA for visualizing identity exploration trajectories is also demonstrated.

Introduction

Research on science, technology, engineering and mathematics (STEM) education has increasingly referenced ways to develop learner skills in identity exploration, or a student's "deliberate internal or external action of seeking and processing information in relation to the self" (Kaplan, Sinai & Flum, 2014, p. 250). This process of self-directed learning can promote identity changes in targeted directions over time, such as taking steps to attain a future STEM career (Martin-Hansen, 2018; Foster, 2014). Experiences that support learning as identity exploration may therefore prove valuable in a 21st century context for supporting adaptive skill development and preparation for emerging and under-accessed STEM careers (Callahan, Ito, Campbell, Wortman & Wortman, 2019). Identity exploration processes hold promise for increasing participation and eventual acquisition of STEM careers among underrepresented gender (Vincent-Ruz & Schunn, 2018) and racial groups (Estrada et al., 2016).

Virtual learning environments such as games and simulations have been identified and researched for their potential to support changes in both cognitive (i.e. knowledge) and affective-related (i.e. motivation) aspects of learning and the self (Portnoy & Schrier, 2019). To rigorously leverage these affordances however, theoretical and pedagogical frameworks are vital to inform the use and design of virtual learning environments (Mikropoulos & Natsis, 2011; Fowler, 2015). The intentional design and inclusion of real-world supportive classroom curricula (Hanghøj, Lieberoth & Misfeldt, 2018) also remains a necessary and important feature. Finally, emerging research on games and identity exploration will benefit from the use of methodological approaches that can illustrate the nuances of student identity exploration as it unfolds across a designed game-based learning experience.

This work leverages the Projective Reflection (PR) theoretical framework to operationalize learning as identity exploration that leads to identity change over time, as facilitated by the immersive interactive affordances that can be found in many game-based learning environments (Foster, 2014). PR was used to design three consecutive iterations of a *Virtual City Planning (VCP)*, a course that leveraged a virtual learning environment (*Philadelphia Land Science*) and supportive in-class curriculum to promote identity exploration of urban planning and environmental science careers. *VCP* was implemented in a museum classroom context with a diverse sample of 54 high school students. This paper examines group identity exploration trajectories over time in *VCP* sessions 1-3 using Epistemic Network Analysis, which is a quantitative ethnographic technique of modeling the structure of connections in student data. Findings (a) illustrate how *VCP1-3* supported statistically significant shifts in student conceptualizations of self over time as defined by PR, (b) reveal similarities and differences in how identity exploration was supported and enacted each session. Implications for games and education practitioners, designers and researchers are discussed. The research question asks: *What is the nature of students' processes of identity exploration over time (as defined by Projective Reflection) in sessions 1-3 of Virtual City Planning?*

Virtual learning environments and STEM identity exploration

Games and virtual learning environments have designed potential to promote situated, targeted, and intentional learning experiences that can be useful for promoting identity exploration. For example, the design of multi-user virtual environments (i.e. Kamarainen, Metcalf, Grotzer, & Dede, 2015) and virtual internships (i.e. Markovetz et

al., 2017) have been found to support authentically *situated* experiences that simulate the practices of real-world STEM professions, allowing students to use and develop community-supported skills, knowledge, values, and mindsets. Digital enrichment programs have shown potential to support learning that is both *targeted* to specific domains and to the specific identities of learners in specific contexts (i.e. middle school girls, (Ogle, Hyllegard, Rambo-Hernandez, & Park, 2017). As such, games have been lauded for their potential to support identity-related constructs such as interest, motivation and self-efficacy around science roles (Portnoy & Schrier, 2019). Not all studies have uniformly been found to support desired cognitive or affective changes in STEM learners, however (Wouters, van Nimwegen, van Oostendorp & van der Spek, 2013), which suggests that the *intentional* examination and design of a virtual learning environment to understanding its capacity to support learning is vital to fully leverage the benefits of the tool (e.g. Clark, Tanner-Smith, & Killingsworth, 2016).

Despite the affordances of games, few empirically tested theories currently exist to operationalize processes of identity exploration along the complex, interconnected, and evolving cognitive/affective features related to learning and self. Research on games and identity has addressed this through the use of the Projective Reflection theoretical framework to structure assessments of student identity exploration. For example, studies of classroom interventions using commercially popular games illustrated how game-based learning experiences can be designed to best support identity exploration if the affordances and constraints of a game environment are first assessed and then supplemented using curricular activities (Foster & Shah, 2016).

Methodological approaches are consequently needed to complement emerging theories such as Projective Reflection by structuring assessment of learning as identity exploration in game-based interventions. Quantitative ethnography (Shaffer, 2017) offers one valuable method for exploring patterns of activity nested in situated discourse. Quantitative ethnographic techniques such as Epistemic Network Analysis (ENA) involve the quantification of qualitative data to generate visualizations that can represent the associations individuals establish across a network of constructs (i.e. identity exploration constructs). ENA has previously been used to characterize what players learn from gameplay in terms of knowledge, skills, values, and habits of mind (Shaffer, Collier & Ruis, 2016), further highlighting the potential of this methodology for illustrating processes of identity exploration as they are enacted by learners using games or virtual environments in formal learning settings.

Theoretical framework

Projective Reflection (PR) is a theoretical framework that defines learning as a process by which participants intentionally explore an activity-based identity through engagement with virtual learning environment, with the potential to engage in domain-specific self-transformation over time (i.e. environmental science and urban planning) (Foster, 2014). PR conceptualizes learning as identity change across four cognitive and affective constructs: knowledge, interest and valuing, patterns of self-organization and self-control, and self-perceptions and self-definitions (see Table 1). Conceptual definitions for each of the four PR constructs were developed from reviews of literature on 21st century learning, motivation, self-regulation, and identity.

The Play, Curricular activity, Reflection, Discussion (PCaRD) pedagogical model offers one way to design and implement a virtual learning environment that support learning as identity exploration. During *play*, student exploration of the role is guided by the design features of the game and game pedagogical supports (e.g. virtual mentors). Depending on player characteristics and the extent to which the game supports role exploration, *curricular activities* that include opportunities for *reflection* and *discussion* are designed as augmentations to virtual environment. These curricular augmentations draw upon students' academic, personal and in-game knowledge and experiences to make the identity exploration personally relevant to each student (Silseth, 2012).

Table 1: Projective Reflection constructs to frame identity exploration and change in environmental science

		Definitions (environmental science context)	Example Lit.
	Knowledge	Shifts in what a player knows about environmental science, urban planning, and related systems from course beginning to end: • *Foundational knowledge*: awareness of complex and domain-specific content and processes that includes the ability to access information using digital technologies • *Meta-knowledge*: awareness of how to use foundational knowledge in relevant socially situated contexts • *Humanistic knowledge*: awareness of the self and one's situation in a broader social and global context	Kereluik, Mishra, Fahnoe & Terry (2013)

Interest and valuing	• Caring about environmental science and urban planning issues and viewing them as personally relevant or meaningful • Shifts in identification with environmental science • Viewing environmental science/urban planning as relevant to the community or world (situational) • Seeing the need for environmental science for self and for use beyond school contexts	Wigfield & Eccles (2009)
Self-organization and self-control	Shifts in behavior, motivation, and cognition toward a goal: • *Self-regulated learning:* independent goal setting and achievement • *Co-regulated learning*: regulation processes supported by more knowledgeable real/virtual mentors • *Socially shared learning*: regulation is socially negotiated in collaboration with peers	Hadwin & Oshige (2011)
Self-perceptions and self-definitions	Shifts in how a participant sees herself in relation to science: • *Self-efficacy*: confidence in ability to achieve goals/future roles • *Self-concept*: awareness of current aspects of self (i.e. skills, preferences, characteristics, abilities, etc.) • Specific roles one wants or expects to become in future	Kaplan, Sinai & Flum (2014)

To assess learner identity change over time, researchers may leverage the four PR constructs as an analytical tool to compare a learner's starting self at the beginning of a designed experience to their new self at the end of the experience. Processes of identity exploration as defined by Projective Reflection are most valuable when students can enact them in an *integrated* fashion. In *VCP*, integration increases when students can begin to regularly connect their Knowledge gains, emerging personal Interests and Values, the enactment of Self-organization and Self-control strategies, and specific Self-perceptions and Self-definitions related to urban planning and environmental science. Given that identity exploration is conceptualized as a developmental process of change over time, it is vital to examine identity integration as not only co-occurrences in a single piece of student data (integration in that moment), but also as a longitudinal relationship between the way a student conceptualizes her "self" in one moment to the next across a meaningful unit of time (the course). As such, Epistemic Network Analysis is a valuable tool to visualize the intricate longitudinal relationships that emerge between PR constructs as students enact identity exploration of environmental science careers over time.

Research methods

This research was conducted as part of a 5-year NSF CAREER project awarded to develop theory and research on promoting student exploration of science identities using game-based learning experiences (Foster, 2014). Researchers designed and implemented three iterations of *Virtual City Planning (VCP)*, which featured weekly use of the virtual environment *Philadelphia Land Science* (*PLS*) and supportive real-world curricular activities (see Shah et al., 2018). Fifty-six Philadelphia high school students participated in *VCP*1-3 from September 2016 to May 2017 (See Table 2). Students were selected for participation by a science museum that coordinated weekly STEM career-related opportunities. Design-based research (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003) informed the development and implementation of *VCP*1-3 to develop analogous urban planning experiences given different course lengths offered by the museum, as well as to refine game and curricular design to more comprehensively support student identity exploration. Though each iteration provided an analogous chronological student experience, (a) *VCP*1 relied heavily on the use of *PLS* with fewer external augmentations, (b) *VCP*2 balanced the use of *PLS* and external augmentations, and (c) *VCP*3 relied almost entirely on in-class gamified activities (for more information on *VCP* design choices and iterations, see Foster et al., 2017).

Table 2: Student demographics for *VCP sessions 1-3*

	Sex	Race/ethnicity	Total
*VCP*1 9 weeks 10/16 – 01/17	6 male 12 female 2 other/no response	4 Caucasian American 6 African American 5 Asian or Pacific-Islander 1 Hispanic or Latino/a 4 Multiple/other	20
*VCP*2	10 male	8 Caucasian American	19

| 8 weeks
01/17 – 03/17 | 8 female
1 other/no response | 6 African American
3 Hispanic or Latino/a
2 Multiple/other | |
| VCP3
4 weeks
03/17 – 05/17 | 8 male
8 female
1 other/no response | 4 Caucasian American
6 African American
3 Hispanic or Latino/a
3 Multiple/other | 17* |

* Two students from *VCP1* were also participants in *VCP3*.

In *VCP*, groups of students were synchronously guided by online and in-person mentors to change zoning districts applied to downtown Philadelphia. As structured by PCaRD, each weekly class involved periods of uninterrupted play. The virtual environment *Philadelphia Land Science* (*PLS*) guided students through roleplay as interns in a fictitious urban planning firm that models real-world professional settings. In *PLS*, students conducted research on stakeholder issues (i.e. carbon monoxide pollution), then iteratively designed city zoning plans on interactive virtual maps that enacted necessary changes. Students then reflected on the process in the form of professional emails. Real-world curricular augmentations were designed to leverage affordances of classroom context to further support identity exploration. For example, museum staff asked students to wear lab coats and act as science professionals, so researchers roleplayed as urban planners to support individual, small group, and large group *reflection* and *discussion*. Another class activity involved group negotiation of city zones on paper maps that allowed learners to reflect on their values and discuss zoning merits with peers.

Data collection

Qualitative and quantitative data was obtained through in-game (e.g. written reflections as urban planning interns) and classroom artifacts (e.g. survey responses). Text data was organized chronologically for each student to track changes in identity exploration processes from beginning to end of *VCP*. After each class, researchers collaborated to write detailed memos of interactions with students; memos were segmented by discussion of student and organized chronologically in each individual's data file. Player data was collected from the following sources:

- A pre and post survey consisting of a) 5-point Likert-style questions (ranging from Strongly Agree to Strongly Disagree on questions such as "I can see myself in an urban planning career in the future") (pre $\rho' = .969$, post $\rho' = .993$), and b) short answer questions (e.g. "describe your interests in learning about cities and the environment"). For the purposes of this study, quantitative data was treated interpretively.

- Responses to writing prompts in *PLS*, framed as professional emails to the design firm.

- Written posts made on an online forum website as a curricular activity.

- Written researcher memos on student interactions, discussions, and activities.

- Screenshots and images of student map designs, from the virtual internship tool and from in-class design activities using paper maps. Images were examined for qualitative analyses but not ENA.

Data analysis

Once data collection and organization was completed, a deductive or directed coding process was applied to each case (Krippendorff, 2004) in which each line of data was coded for self-reflection on/demonstration of one or more aspect of identity exploration (as defined by PR), with agreement reached by two graduate-level coders. Lines were coded for the occurrence (1) or non-occurrence (0) of the four PR constructs to prepare for visualization of identity exploration patterns using Epistemic Network Analysis (ENA) (Shaffer, 2017). For example, a student's reflection reading, "the big ones [issue] I care about is pollution," was coded (1) for interest and valuing. ENA is a quantitative ethnographic technique for visualizing the connections between constructs that functions under the following assumptions: (a) that it is possible to systematically identify meaningful features in data (codes); (b) that the data has local structure (conversations); and (c) that an important feature of the data is the way that codes are connected to one another within conversations (Shaffer et al., 2016). A single piece of student data (written, observed) may be representative of change in one or more codes (the PR identity constructs).

ENA generates network visualizations of the co-occurrence of codes within a moving stanza window, which means that codes applied to one line of student data are connected to each other and to codes applied to the previous 3 lines of chronological student data (as recommended by Siebert-Evenstone et al., 2017). This process is appropriate given the conceptualization of identity exploration as a developmental process of change. Epistemic networks that summarized code relationships by session were generated for the first half (Time 1) and second half (Time 2) of *VCP* 1-3 to explore how identity exploration shifted over time as supported by each iteration. ENA

analyzes all chronological networks simultaneously so that they can compared visually and statistically. To achieve this, models normalize the networks for all units of analysis before they are subjected to a dimensional reduction, which accounts for the fact that different units of analysis may have different amounts of coded lines in the data (see Shaffer et al., 2016). Epistemic networks were generated for Time 1 and Time 2 for each session to compare differences and similarities within and across them over time. Paired-samples t-tests were completed to test whether changes from Time 1-2 in each session were statistically significant along the X and Y axes. The results also reference themes identified from qualitative studies of the data (i.e. Foster, Shah, Barany & Talafian, 2019) to close the interpretive loop and provide deeper understand the phenomena visualized in the models.

Findings and discussion

To answer the question "What is the nature of students' processes of identity exploration over time (as defined by Projective Reflection) in sessions 1-3 of *Virtual City Planning*?" the overall means for Session 1-3 are presented to understand design or cohort differences across sessions. In addition, means for Time 1 and Time 2 for each session are presented to illustrate chronological trajectories of identity exploration enacted by each cohort over time. Figure 3 illustrates the positionality of (a) squares that represent the overall means for sessions 1, 2, and 3 network data, and (b) labelled circles to represent the breakdown of Time 1 and Time 2 means for each session. The movement of means from Time 1 to Time 2 for each session is illustrative of the changing ways in which the same cohort of students connected the four Projective Reflection constructs to each other (e.g. changes in integration) across two time periods. The different locations of the 3 summary means for sessions 1-3 are illustrative of differences between cohorts in terms of how they enacted their identity exploration processes.

Figure 3. Network means by overall session (square) and broken down by time period (circle).

Figure 4 presents the same network means (overall and by time) with the epistemic network of relationships between the four Projective Reflection constructs overlaid. This epistemic network serves as a map for interpreting the direction of mean differences and movement over time. For example, compared to the overall means for Sessions 2 and 3, the overall mean for Session 1 is skewed toward the Knowledge construct, suggesting that students in Session 1 more regularly discussed or demonstrated knowledge-related growth or change. This finding is supported by prior examinations of the *curriculum elements* in *VCP1,* which featured more use of the virtual city zoning tool and more reflections on emerging understanding of the role through professional emails.

Characteristics of *the cohort of students* also had potential to shift the overall mean of a session. For example, a qualitative review of Session 2 student data revealed that more members of this group were able to explicitly discuss their self-perceptions and self-definitions as they related to their urban planning identities over time. For example, Bethany reflected early in the session that this was the first time she had been prompted to think about future careers or roles, while students such as Mateo were thinking about looking for jobs near the end. Some students in Session 2 reflected that they could see themselves as urban planners, either during the course itself or potentially after, while others remained unsure of what future roles they might pursue but did not rule out urban planning. Students such as Elijah recognized how urban planning was valuable topic for him to understand as a future business owner. While the ways in which students in Session 2 described their self-perceptions and definitions differed in content, the group was more able to explicitly engage in reflection and discussion on the topic, as demonstrated by the skewing of the Session 2 overall mean toward this construct.
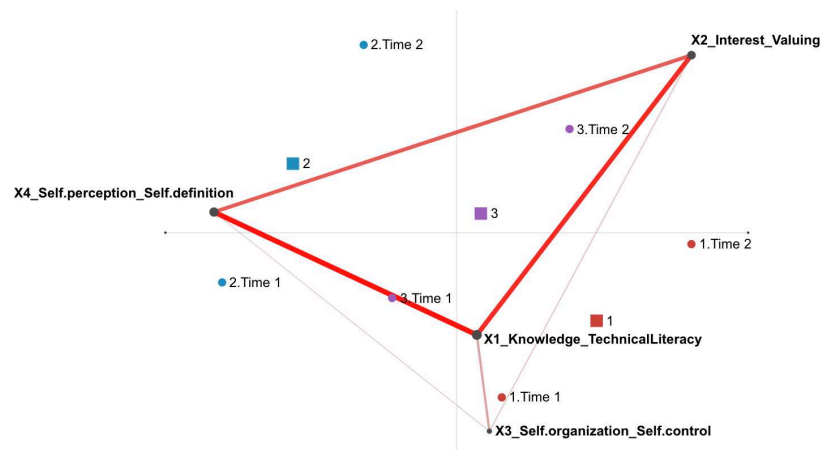
Figure 4. Network means with the epistemic network of constructs overlaid.

The overall mean for Session 3 is more centrally located than those for Session 1 and 2, which suggests that students' discussions of and connections to the four PR constructs may have been enacted in a more balanced or integrated manner. Quotes like the following from Oliver (pseudonym) illustrate how students were able to more readily connect emerging knowledge, interests and valuing of the topic, and self-perceptions/definitions as Philadelphia residents and urban planning interns over time:

> I care a lot about having plenty of green areas [open spaces and wetland preserve zoning] for kids to play in and explore. Nature is a beautiful thing, I've found some places with overgrown grass and trees in Philadelphia. Exploring those places with friends is an amazing thing, and I feel like we should have a lot of places like that.

An examination of shifts in mean positionalities from Time 1 to Time 2 for each session reveal striking commonalities with regard to the trajectory of identity exploration that students enacted over time. First, to determine whether student changes from Time 1 to Time 2 were statistically significant for each session, three paired-samples t tests assuming unequal variance were conducted between the X and Y axes of Time 1 and Time 2. These t-tests measures differences between the structure of connections; therefore, N refers to the number of nested units of session data. For example, Time 1 of Session 1 has 264 units of classroom activity data across the weeks and students in that sample. Along the x axis for each session of *VCP*, a two-sample t test assuming unequal variance showed that Time 1 *was* statistically significantly different from Time 2 at the alpha=0.05 level. Along the y axis for each session of *VCP*, a two-sample t test assuming unequal variance showed that Time 1 *was not* statistically significant from Time 2 at the alpha=0.05 level (See Table 2).

Table 3: Paired sample t-test statistics

		N	Mean	SD	t	df	Sig. *(2-tailed)*	Cohen's d
Session 1 X-axis	Time 1 (Week 1-4)	264	-0.10	0.71	-3.29	500.18	0.00*	0.27
	Time 2 (Week 5-9)	365	0.07	0.59				
Session1 Y-axis	Time 1	264	0.00	0.59	0.00	574.43	1.00	0.00
	Time 2	365	0.00	0.61				
Session 2 X-axis	Time 1 (Week 1-4)	229	-0.20	0.87	-4.89	461.17	0.00**	0.44
	Time 2 (Week 5-8)	287	0.16	0.78				
Session 2 Y-axis	Time 1	229	0.00	0.61	0.00	477.83	1.00	0.00
	Time 2	287	0.00	0.58				
Session 3 X-axis	Time 1 (Week 1-2)	95	-0.14	0.43	-3.83	205.00	0.00***	0.52
	Time 2 (Week 3-4)	113	0.12	0.55				
Session 3 Y-axis	Time 1	95	0.00	0.40	0.00	205.97	1.00	0.00
	Time 2	113	0.00	0.47				

$*R^2 = .017, **R^2 = .045, *** R^2 = .065$

Statistically significant changes across the X axis can be understood from a visual examination of the network means (See Figure 4) as a shift across sessions toward deeper and more frequent student connections to interest and valuing around urban planning and environmental science careers. This shift in means towards the Interest and Valuing construct suggests that regardless of differences in cohort or in the design and implementation of *VCP,* the course encouraged deeper, more frequent, and more integrated student reflections on the value, relevance, and utility of urban planning and environmental science roles for themselves and their communities. This suggests that play-based courses whose design was informed by Projective Reflection can support domain-specific identity exploration as Kaplan and colleagues (2014) defined it: the "deliberate internal or external action of seeking and processing information in relation to the self" (p. 250). Final reflections of students illustrate these shifts: (a) James wrote "My interest in learning about my Philadelphia's environment is really [of concern], because I live here and it's not a pretty site to live in quite frankly, and I think that should change," and (b) Ali wrote "i can see myself being a construction worker, on the urban planning things that i know that i can change, it would be easy for myself to create the open space for the people in my neighborhood."

Conclusion and implications

Results illustrate the utility of educational experiences designed to facilitate Projective Reflection (Foster, 2014) for supporting students' increasingly integrated processes of identity exploration related to STEM domains (i.e. environmental science and urban planning). Though characteristics of a specific designed experience or student cohort may result in some differences in the overall identity exploration process, trajectories of identity exploration over time manifested as increasing and statistically significant change toward student discussions of their interest and valuing of a topic. Over time, students used science knowledge to achieve personally relevant learning goals in the situated environment and demonstrated more detailed awareness of the relevance and value of the topic for themselves in the present and future. These findings align with summary reports on the acquisition of STEM careers, which suggests that identity exploration may be closely linked to students' developing interest and motivation around a topic, resulting in closer and deeper engagement with the topic over time (CAISE, 2018). Given these findings, designed virtual learning environments such as *Virtual City Planning* have potential to serve as particularly valuable avenues for promoting the exploration (and potential future acquisition) of STEM identities across longer time periods and with a more diverse group of students based on the capacity of such environments to adapt to individual and contextual needs and connect learning to the self.

Quantitative Ethnographic (QE) (Shaffer, 2017) techniques such as Epistemic Network Analysis (ENA) served as a valuable and innovative approach for understanding whole-group trajectories of identity exploration as operationalized by Projective Reflection. ENA not only allowed researchers to examine large quantities of student data related to identity exploration by providing a nuanced view of the relationships between identity constructs (integration), but also supported comparison of group characteristics over time (Time 1 to Time 2). Future reports will expand on this inquiry to interpret and compare the weighted connections (line thickness) between PR constructs across different times and sessions. Future studies will test and refine new virtual learning environments that can facilitate Projective Reflection in different contexts, and also incorporate methods such as Social-Epistemic Network Analysis (See Gašević et al., 2019) to examine identity exploration as both an individual/developmental and collective/situational process of change over time.

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