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Principle-Focused Evaluation for STEM Persistence

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Abstract
In postsecondary STEM programs retention of students is challenging. This paper presents a principle-focused evaluation system to be applied to STEM education programs in higher education institutions to optimize student persistence. We transformed a STEM education persistence framework developed to increase STEM student retention in higher education into a set of evaluation principles. We argue that these principles provide higher education institutions with a novel practical frame for system-wide development and evaluation of their STEM education programs. Application of our principles will increase STEM education retention and inherently will improve program quality for individual students, courses, programs, and the overall institution.

Keywords: *STEM education, principle-focused evaluation, persistence, retention.*

1. Introduction

Students in STEM disciplines graduate at a substantially lower rate than students in non-STEM fields (Sithole et al., 2017), and this is particularly true for women and under-represented minority students, even though the gender gap is slowly closing (Seymour & Hunter, 2019). Enhanced persistence has been identified as a key element in reducing the number of students leaving STEM disciplines in higher education (Seymour & Hunter, 2019). The literature provides a range of recommendations for best practices and interventions to address attrition in college STEM programs (Graham et al, 2013; Green and Sanderson, 2018; Kuh, 2013; Sithole et al., 2017). A range of assessments measuring persistence factors such as motivational constructs are available (Simon et al., 2015). Overall, however, persistence in STEM education depends on the overall program quality and student experience (Xu, 2018). What is missing is an evaluation strategy that can integrate available assessments and informal feedback in a simple, systematic, sustainable way across interventional scales, from classroom to institution. Principle-focused evaluation (PFE) (Patton, 2017) provides an intriguing approach, but to date, there are no STEM persistence principles articulated for higher education. The work presented here describes our efforts to build a set of STEM education principles for use with PFE based on best practices in STEM persistence to help guide the development and evaluation of STEM persistence interventions across scales.

In 2013, Graham et. al elegantly summarized more than a decade's worth of research into persistence and developed a framework focused on interventions that enhance science learning and professional identification as a scientist as main determinants of persistence. They center early research experiences, active learning environments, and the development of learning communities as interventions that drive STEM learning and identification as a scientist, both of which reinforce confidence and motivation, which are critical to continued persistence. Their framework was explicitly developed to guide both the development and assessment of intervention efforts (Graham et al., 2013), and its framework has been used extensively for program development. However, to date, there has been little work using the framework as an assessment tool to compare STEM persistence intervention efforts between programs and across scales. As an example, DiBartolo et al. (2016), explicitly calls out the lack of coordinated assessment of STEM persistence efforts across institutions that share common STEM intervention efforts. Part of the reason for this is the evaluation challenge when comparing across diverse, complex, and complicated settings.

Patton (2017) proposed a system of principles-focused evaluation to evaluate interventions in just such circumstances. Principles are statements that guide actions and behaviors toward a desired result and to be effective, they must meet the criteria of being guiding, useful, inspiring, developmental, and evaluable. *"This framework prioritizes a values-based process for creating institutional change: Given the uncertainties of complex interventions and interactions, where the ends (outcomes, impacts, results) are uncontrollable, unpredictable and emergent, values can become the anchor, the only knowable in an otherwise uncertain, unpredictable, uncontrollable and complex world"* (Patton, 2017, p. 121, *emphasis in original*)." Much like adaptive management practices, PFE is a way to address the complex, multifaceted challenges present in higher education STEM student retention.

In this paper, we give a brief overview of our use of the PFE framework to develop the intervention recommendations of the Graham persistence framework into principles that can guide the development and evaluation of STEM persistence programs across scales.

2. From Intervention to Principle

In their framework, Graham et al. (2013) point to three key interventions, activities known to positively impact STEM persistence: active learning in introductory courses, early research experiences, and membership in STEM learning communities. These activities are framed by the determinants of persistence, increased confidence and motivation, and STEM identity and learning. All have significant grounding in best practices for STEM persistence and are widely recognized and researched as practices that support student retention.

What Graham et al. (2013) did not do is articulate principles for evaluation, though the three activities are well positioned as such. To operationalize Graham's activities as principles for PFE we assess the Graham et al. (2013) activity language using the PFE principles guide (Patton, 2017, p. 38) and modify it as needed to derive principles ready for programmatic development and evaluation use.

2.1. The GUIDE to Principle Development

Patton (2017, p. 27) states that "the distinguishing characteristic of principles-focused evaluation is the focus on principles as the object of evaluation, as the evaluand". Thus, a principle must first be articulated and evaluated for its utility in PFE and Patton provides a framework and rubric for this assessment. The GUIDE framework assures that a principle is *(G)uiding*, *(U)seful*, *(I)nspirational*, *(D)evelopmental*, and *(E)valuable*. Briefly, the GUIDE looks at the prescriptiveness of a principle (Patton, 2017, p. 38). According to Patton, to provide high utility, a principle should be instructive and provide direction to be considered *guiding*. A *useful* principle explains its effectiveness. Principles *inspire* when they are grounded in purpose providing value-based meaning. Being applicable across circumstances and time makes a principle *developmental*. And finally, the principle is *evaluable* when it facilitates documentation and assessment. Following this GUIDE, principles can be developed that catalyze a whole range of aspects relevant to program quality and evaluation thereof.

2.2. Development of Sustainable STEM Education Principles

Having highlighted the existing aspects of a PFE-aligned principle present in the Graham framework, we constructed a series of "ARC" principles built on the (A)ctive learning, (R)esearch experiences, and learning (C)ommunities interventions recommended by the Graham framework. The construction process involved a recursive review of wording that captures the Graham framework key activities while following the guidance of Patton on reviewing and reflecting on the principles until they adhere to all five GUIDE criteria for principle-focused evaluation.

Guiding principles are prescriptive by saying what to do (Patton, 2017). The Graham interventions, however, are static statements of best practice but do not provide guidance. Patton emphasizes adding action verbs to provide direction such that a principle becomes transferable across systems (Patton, 2017). Thus, we add the language ***engage students***, ***provide authentic,*** and ***facilitate membership***, to the principles to provide organizations specific, actionable guidance on what they should be doing to increase STEM persistence.

The *usefulness* of principles is given when they provide specific guidance for application (Patton, 2017). The Graham framework, as developed from the research, gives examples and references that provide the reader with specific applications of all three activities. Thus, the activities as Graham et al. (2013) articulates them already speak to the useful directions for making choices and guiding implementation. Therefore, the principles provide utility by pointing at the praxis of providing ***active learning practices***, ***research experiences***, and ***learning communities***.

Inspirational means that principles are values-based, ethically grounded, meaningful, important, and evoke a sense of purpose (Patton, 2017). From the theoretical underpinning of the three Graham activities, we can see that they all center on students and the student experience. Experiential learning theory (Kolb, 2014), which roots early learning experiences, and constructivism theory, in which active learning and learning communities are grounded, all focus on the importance of personal and shared experience and learning. Thus, activities are to be implemented ***so students construct STEM learning, so students develop and build a professional STEM competency,*** and ***so students empower each other and learn collaboratively***.

The *developmental* nature of a principle shows when it clearly points to a way to implement it across systems, continuously, and with recursive evaluation. The path for this is not clearly provided by Graham. Arising from best practices for STEM programming (Graham et al., 2013), the program-specific context is easy to envision. However, to enhance STEM persistence among diverse groups and across a diversity of programs and scales we need to ask the question if there is the flexibility to interpret these principles to apply across contexts. By adding the language ***on a regular basis, early on and throughout their education,*** and ***sharing education experiences across generations*** to the principles we address that all principles need to be implemented across grade levels and scale, from the individual experience to the institutional level.

Evaluable means that the principles lend themselves to be tools for evaluation. The Graham framework names two determinants of persistence, learning gained and scientist identification, and two cognitive indicators of persistence, motivation and confidence. Published measures and validated assessments for all of these are available in the literature (e.g. Summers and Hrabowski, 2006; Matsui et al., 2003; Murphy et al., 2019). We included language in the principles that identify the measurables. The principles describe the outcome for the students: active learning **is *leading to their increased STEM learning***, research is ***increasing their STEM identity***, and communities are ***enhancing their motivation and confidence***.

As fully articulated the ARC principles read:

(A)ctive Learning Principle: engage students in active learning practices, so students construct STEM learning, regularly, increasing their science learning outcomes.

(R)esearch Engaged Principle: provide authentic research experiences, so students develop and build a professional STEM competency, early on and throughout their education, increasing their STEM identity.

(C)ommunities Focused Principle: facilitate membership in STEM learning communities, so students empower each other and learn collaboratively, sharing education experiences across generations, enhancing their motivation and confidence.

Table 1. STEM ARC Principles Alignment with PFE GUIDE Elements.

	Active Learning:	**Research Engaged:**	**Communities Focused:**
(G)uiding	engage students	provide authentic	facilitate membership
(U)seful	in active learning practices,	research experiences,	in STEM learning communities,
(I)nspirational	so students construct STEM learning,	so students develop and build a professional STEM competency,	so students empower each other and learn collaboratively,
(D)evelopmental	regularly,	early on and throughout their education,	sharing education experiences across generations,
(E)valuable	increasing their science learning outcomes.	increasing their STEM identity.	enhancing their motivation and confidence.

Importantly, the ARC principles do not give siloed cause-and-effect rules but provide a tool that guides the continuous development and evaluation of STEM programs. For example, while the application of all three principles increases STEM learning, identity, motivation, and confidence, we chose to not link all four outcomes to all three principles. Rather we created the principles by linking the most established correlations and frameworks into one principle based on the practical ability to measure and evaluate. Application of the ARC evaluation encourages implementation of all three principles in tandem and we encourage institutions to make cross-connections between the aspects of the three principles to add richness to the interpretation of their evaluation. Using just three principles creates a simplifed picture on STEM persistence for all involved.

3. Utilization of ARC Principles for Evaluation

The ARC principles can be used to derive both process and outcome evaluation questions targeted to the scale of interest (student, course, department or program, and institutional). Using the example of the Active Learning Principle, process evaluation questions at different scales might be: What percentage of students expressed in interviews that they were engaged in active learning (student level)? How frequently did the faculty use active learning practices (course level)? How were active learning efforts supported (department or program)? What guidance was provided to focus the institution on active learning (institutional)? Outcome evaluation questions might be: Did active learning change student motivation or confidence (student level)? Did it change students' understanding of STEM material? (course level) Was active learning applied across teaching modalities (department or program)? Did active learning implementation result in higher student persistence (institutional)?

Importantly, evaluation is not just the summative assessment of outcome data but can expand to be applied in a self-sustaining cycle where positive and negative evaluation outcomes drive the continuous design and coordination of programs. For example, in a pilot application of the ARC principles in 2018-2019, instructors and program administrators of the University of Idaho TRIO STEM Access program reviewed the principles during initial planning meetings where team members took time to talk about what implementation of the principles may look like. Subsequently, during program meetings the principles anchored progress discussions, they were assessed with survey and student focus groups at the completion of the program, and they were evaluated in a post-program triangulation meeting leading to an internal report. The initial personal conversation about what the principles looked like invigorated the team to fortify the program in small ways while yielding a type of STEM learning program where students highlighted those improvements as beneficial.

As described above, the principle-focused evaluation is ideally situated to provide such a sustainable mechanism by grounding all evaluation and program development in the principles. Thus, the principles developed for STEM persistence, Active Learning principle, Research Engaged principle and Community Focused principle, provide an arc from development to evaluation.

The application of the ARC principles is limited by familiarity with the principles and the extent to which they are utilized. At a minimum, an evaluator familiar with the principles gathers data available and feedback to create a summative evaluation. This can determine if a program is aligned with the ARC principles, however, this is insufficient for creating a culture of STEM persistence, as it can only yield information on where efforts need to be directed. At full implementation, all members of the departments delivering STEM instruction are familiar with the ARC principles and the principles guide program planning, are implemented throughout program delivery, and form the basis for program evaluation. Lessons learned from previous efforts then inform subsequent efforts. This intentional circular feedback approach leads to adaptive, sustainable approaches to enhancing STEM persistence.

Further development of the ARC principles is needed. A comprehensive literature review will identify existing assessments that can be used to measure components of these principles at different institutional scales. Understanding which of those are currently used by postsecondary intuitions to understand STEM persistence can surface the gaps in comparison with the more comprehensive approach of the ARC principles. Research on the ARC principles implementation in case studies will provide further insight into their effectiveness for increasing STEM persistence, and how this looks when sustainably implemented.

4. Conclusion

This conceptual paper transforms the Graham STEM Persistence framework into the ARC principles for use with PFE. While PFE has been successfully applied across a range of programs in higher education, principles designed specifically for STEM persistence are new. Our articulation of these ARC principles aligns with Patton's GUIDE criteria for principle development. Formulation of the principles in this manner allows the principles to be used for both program evaluation and development across programmatic scales, enhancing their utility for comparing STEM persistence efforts across diverse and complicated contexts. A pilot application of the principles indicates the efficiency of this approach but also highlights that full implementation requires wide dissemination and adoption of the ARC principles at all levels of program management. Furthermore, when used exclusively as an evaluative tool, the ARC principles are unlikely to enhance STEM persistence, so should be paired with iterative and adaptive principles-based program development. Finally, more work is needed to identify existing assessment tools that can be evaluated within the ARC principle framework and to identify assessment gaps that require further development efforts.

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