Niche Construction as an Ecological Analog for Improving Educational Systems

NADIA KELLAM & DAVID GATTIE
University of Georgia, USA

WALLY PETERS
University of South Carolina, USA

In living systems, niche construction is the phenomena in which organisms define and create their own niches through their metabolism, activities, and choices. The authors of this paper have developed a program that borrows the concept of niche construction from living systems and applies it to higher education to encourage a healthier educational system. This program requires that the students fulfill fundamental program requirements, but beyond those requirements they are responsible for designing a niche that best suits their abilities and interests. Each student's niche is developed using a continuous improvement loop (plan, do, check, act, plan …) and is based on their personal vision and objectives. This proposed educational niche program has the following characteristics in common with healthy, living systems:

· Requires participation from every student,
· Encourages diversity,
· Organizes itself,
· Motivates students to take an active role in their success (self-preservation),
· Generates feedback within the system,
· Encourages competition and cooperation amongst the students, and
· Encourages students to become adaptive experts.

Details of the educational niche program will be discussed; this will include a discussion of niche construction in ecological systems and educational systems, examples of niche construction educational programs, and potential tensions that may develop when implementing this program.

Proceedings of the 2007 Complexity Science and Educational Research Conference
Feb 18–20 • Vancouver, British Columbia • pp. 145–155 • www.complexityandeducation.ca

Introduction

Engineers are very comfortable working in a world based on the philosophy developed by Francis Bacon, Renè Descartes, and Isaac Newton. While a strict adherence to this Newtonian philosophy and the scientific method has served society well in fields of engineering, physics, chemistry, and biology, it has limited application to systems that involve humans, such as educational systems (Gattie, Kellam, & Turk, 2007). Traditional engineering disciplines have matured largely due to their success using the scientific method in isolating objects from their environment, learning their behaviors under tightly controlled conditions, and subsequently designing systems of parts that maintain these conditions and provide a function to society (see the left column of Table 1). However, such reductionistic approaches to education are severely detrimental if necessary relationships are severed in order to isolate individuals or subject matter. This paper proposes a model for learning systems that recognizes the reality that educational systems are not as predictable and controllable as Newtonian systems and that the interrelationships between the parts of an educational system are critical to the behavior of the system as a whole and the parts of the system. Much of engineering education research is currently conducted within the Newtonian worldview framework. This project is proposing to transition to a systems approach to understanding learning systems, an approach that values systems properties such as synthesis, open boundaries, connections, network indirect effects, and emergence (see the right column of Table 1).

While this paper is not suggesting that the rigor of Newtonian thinking be abandoned, it is suggesting that the tendency to apply mechanistic, reductive analysis to complex systems should be addressed. According to Bertalanffy (1969), a founder of General Systems Theory, in order to effectively apply mechanistic analysis to a system two conditions must be fulfilled: 1) the interactions between the parts are

Traditional Engineering (Newtonian Worldview)	**Systems & Engineering Ecology (Systems Worldview)**
Mechanical	Organic
Closed	Open
Objects and Elements	Systems and Subsystems
Reduction	Synthesis
Isolation	Connections and Relationships
Control	Management/ Facilitation
Prediction	Insight and Understanding
Functionally Decomposable	Relationally Non-Decomposable
Artifact	Model
Direct Effects	Network Indirect Effects
Design	Emergence

TABLE 1. Characteristics of a Newtonian worldview and a systems worldview (adapted from Gattie, Kellam, & Turk, 2007)

nonexistent or weak and 2) the relations describing the behavior of a system must be causal (linear, cause and effect). In educational systems, these conditions are rarely, if ever met; therefore a systems approach to understanding educational systems is going to be proposed in this paper (Radford, 2007).

In Bateson's book Mind and Nature (1979), he discusses the similarities between the mind and natural systems. He proposes the following list of criteria of mind:

1. "A mind is an aggregate of interacting parts or components.
2. The interaction between parts of mind is triggered by difference.
3. Mental process requires collateral energy.
4. Mental process requires circular (or complex) chains of determination.
5. In mental process, the effects of difference are to be regarded as transforms (i.e., coded versions) of events which preceded them.
6. The description and classification of these processes of transformation disclose a hierarchy of logical types immanent in the phenomena."

He then argues that thought, ecology, life, and learning meet this list of criteria. Bateson has laid the foundation to a better understanding of learning systems through a better understanding of ecological systems.

The premise of this paper is to use an ecological analog of niche construction to develop a program that would encourage systemic change in the higher educational system. While this program is applicable across many disciplines, the authors are engineers; therefore the examples and context will be engineering education. The authors of this paper have developed a program that borrows the concept of niche construction from living systems and applies it to higher education to encourage a healthier educational system. This program requires that the students fulfill fundamental program requirements, but beyond those requirements they are responsible for designing a niche that best suits their abilities and interests. Details of the educational niche program will be discussed in the remaining paper; this will include a discussion of niche construction in ecological systems and educational systems, examples of niche construction educational programs, and potential tensions that may develop when implementing this program.

Niche Construction

Niche construction is the phenomena in which organisms define and create their own niches through their metabolisms, activities and choices (Odling-Smee, Laland, & Feldman, 2003). Scientists have traditionally recognized natural selection as the single driving force for evolutionary changes in organisms. Natural selection is the process by which the environment selects organisms because their genes and traits are in line with those of the local environment (Odling-Smee, Laland, & Feldman, 2003). This is a very passive process for the organisms involved—they either have the traits that are well suited for the environment or they do not. Over many generations, the fittest organisms are the ones that live and reproduce and therefore the organism with the needed trait is the one that survives. This is called genetic inheritance and can be seen in Figure 1.

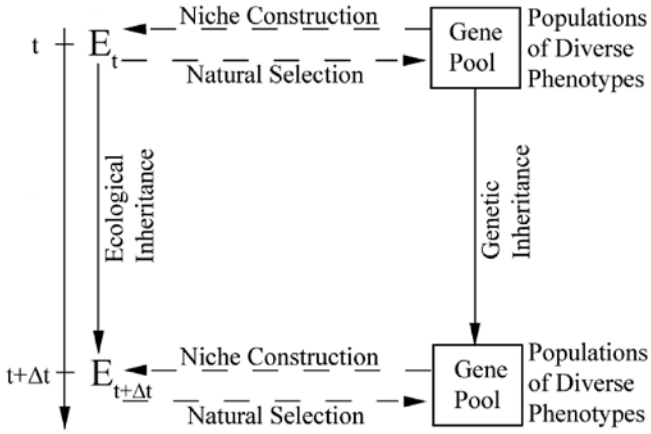

FIGURE 1. Niche Construction and Natural Selection in Ecology
(from Odling-Smee, Laland, & Feldman, 2003, 14)

Niche construction is a process that has a significant part in evolution, although it is less recognized by scientists (Odling-Smee, Laland, & Feldman, 2003). In niche construction, the organisms actively influence their environment so that the environment is a better fit for their characteristics (see the niche construction arrow in Figure 1). The organisms either change their environment so that their behaviors and characteristics are more in line with their environment or the organisms change their location so that they are in a better suited environment for their abilities (See Table 2). Perturbation describes a change in the environment and relocation describes a move to a different environment. In changing the environment for their benefit, they are also changing it for future generation's benefit (or detriment). Within niche construction, the organisms either initiate a change in an environmental factor (inceptive niche construction) or they respond to a change in an environmental factor (counteractive niche construction) (See Table 2).

Niche construction in educational systems would encourage the students to take an active role in their learning (See Figure 2). Students that are naturally predisposed for studying a specific discipline will still be good matches for that discipline's

	Perturbation	Relocation
Inceptive	Organisms initiate a change in their selective environment by physically modifying their surroundings. *e.g., emission of detritus*	Organisms expose themselves to a novel selective environment by moving to or growing into a new place. *e.g., invasion of a new habitat*
Counter-active	Organisms counteract a prior change in the environment by physically modifying their surroundings. *e.g., thermoregulation of nests*	Organisms respond to a change in the environment by moving to or growing into a more suitable place. *e.g., seasonal migration*

TABLE 2. Categories of Niche Construction in Ecology
(from Odling-Smee, Laland, & Feldman, 2003, 47)

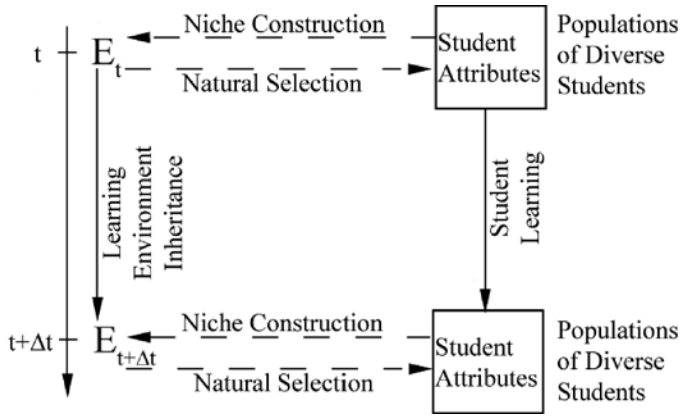

FIGURE 2. Niche Construction and Natural Selection Adapted for an Educational Program (Adapted from Odling-Smee, Laland, & Feldman, 2003, 14)

learning environment (natural selection), but students would also be active players in their environment and make changes to their environment to better match their interests and abilities (niche construction). This would lead to a more diverse set of students in different disciplines, which is important in a time when the students in areas of science, math, and engineering are very homogeneous. Currently there is at least one type of niche construction that is prevalent in higher education—relocation (See Table 2). Relocation involves the students moving to a new environment and can be inceptive or counteractive. Inceptive relocation occurs when a student initiates a change in the environment, for example a student may change their major to one that is a closer fit to their abilities and interests better. Counteractive relocation occurs when a student responds to a change in their environment by moving to a new location. An example of this is when a student transfers to another major or drops out of college in response to not doing well in their freshmen engineering courses. Developing an educational program that allows for the students to make perturba-

	Perturbation	Relocation
Inceptive	***Students*** initiate a change in their selective environment by ~~physically~~ modifying their surroundings. ***e.g., a student initiates a change in the course***	***Students*** expose themselves to a novel selective environment by moving to ~~or growing into~~ a new place. ***e.g., a student selects a new major***
Counter-active	***Students*** counteract a prior change in the environment by ~~physically~~ modifying their surroundings. ***e.g., student resistance to active learning***	***Students*** respond to a change in the environment by moving to ~~or growing into~~ a more suitable place. ***e.g., students change study groups or their position in the classroom***

TABLE 2. Categories of Niche Construction Adapted for an Educational Program (Adapted from Odling-Smee, Laland, & Feldman, 2003, 47)

tions to the environment would make them active agents in the system (See Table 2). Inceptive perturbation to the environment in a learning system is a student initiating change in the classroom or curriculum. This could be as simple as requesting that the teacher talk slower or that less content is covered. Counteractive perturbation to the environment is a student responding to a change in the classroom or curriculum. An example of this is a student's resistance to active learning by not engaging in the classroom assignments. These changes in the environment could also change the environment for future generations of students. A student will always make a change to their environment for a positive initial reason, although it may be to their detriment over a longer period of time or for future generations.

Traditionally, many disciplines have operated on a principle that only certain students can become graduates of certain programs—students that have innate capabilities that lend themselves to that particular field. This is similar to natural selection in that the student is passively awaiting for the environment to determine whether their attributes align with a specific field of study (See Figure 2). When the student is in a traditional, lecture classroom, they passively receive information and those that develop a good understanding of that material are successful, while those that do not are unsuccessful. The classroom environment (teachers, classroom, course content, number of students, interactions between students, and desk arrangement) is not traditionally something that the students have the ability to change (especially not systemically). At most, students complete an end-of-semester course evaluation which could be used to change future iterations of that course taught by the same instructor. How would the educational system be different if the students could make changes to their environment? How would this effect future generations of students?

The characteristics of graduates of a natural selection educational program would likely be different from the characteristics of graduates of a niche construction educational program (See Table 3). In the traditional natural selection educational program, students are passive participants. The environment (college or department) determines whether or not a particular student is 'good enough' to continue in that environment. This is very different from the niche construction program where the students are active participants. The students have the ability to change the environment to better match their abilities and interests. The natural selection educational program encourages homogeneity amongst its participants, while the niche construction program encourages diversity. The natural selection educational program has top-down organization, while the niche construction educational program is self-organizing. In the natural selection educational program there is little to no feedback within the system, at most there are student surveys that are administered at the end of each semester. In the niche construction educational program the participants generate feedback to the system, which in turn changes the environment for future participants. In the natural selection educational program there is an emphasis on competition; the mindset being that only the best and brightest will survive. In the niche construction educational program there is an emphasis on competition as well as cooperation. As a cohort of students, the participants can affect change to the environment. Students will complement each other with their diverse interests and abilities. In the natural selection educational program the

Characteristics of natural selection educational program	Characteristics of niche construction educational program
Students are passive participants	Students are active participants
Encourages homogeneity	Encourages diversity
Top-down organization	Organizes itself
Little to no feedback in system	Generates feedback
Encourages competition in the system	Encourages competition and cooperation
Encourages the students to become competent in content knowledge	Encourages students to become adaptive experts

TABLE 3. Characteristics of participants in a natural selection educational program versus those of a 'niche construction educational program

students are encouraged to become competent in content knowledge. There is a focus on covering as much content as possible. In the niche construction educational program the students are encouraged to become adaptive experts. They learn the skills to become lifelong learners and to take responsibility for the competencies that they need to attain. This is not an exhaustive or conclusive list of characteristics of the natural selection and niche construction educational programs. As programs become developed that infuse the principles of niche construction, assessment can be done to determine whether program participants gain characteristics associated in this paper with the niche construction educational program.

Examples of Informing Educational Programs with Niche Construction

This section will describe examples of ways to incorporate the concept of niche construction into an existing curriculum and into a new curriculum. A program that allows students to make perturbations to the environment will result in a closer match between the students interests and abilities and those of the program. A program that embraces niche construction will need to be flexible enough to allow for the students to make changes, while maintaining its fundamental rigor.

The University of Georgia is currently developing a new set of programs within the Faculty of Engineering while maintaining two degree programs within the Biological and Agricultural Engineering Department within the College of Agricultural and Environmental Sciences. The existing departments are undergoing a revision of their curricula while the new engineering degree programs are being developed. While it is a great opportunity to create a degree program from scratch, this is not typically an option at most universities. Therefore, the revision of the general engineering department's curriculum will be more applicable to most readers, while the new engineering program will provide some elaboration of the possibilities of a niche construction approach to curriculum development.

The existing general engineering program at the University of Georgia is a typical engineering program. The curriculum consists of liberal arts, mathematics, sciences, and engineering sciences courses. The curriculum consists of 30 hours of electives (10 courses), but these courses are engineering courses (with a few exceptions) that are chosen by the student from a list of option courses (15 hours are required) and

a list of area of emphasis courses (15 hours are required). The areas of emphasis include electrical and electronic systems, mechanical systems, structural systems, and natural resource management. The liberal arts courses are in alignment with the college's general education requirements and include two introductory English composition courses, a cultural diversity course, a speech course, and 4 social science courses. Overall this curriculum is very rigid and contains 131 hours (averages to over 16 hours per semester for eight semesters). Typically it is a minimum of 4.5 years for a student to graduate from this engineering program. A transfer student or a student wishing to earn a minor or double major will expect to spend many additional semesters as an undergraduate student.

Advising students in this program is very easy—it simply requires ensuring that the courses are taken in the correct order. There is very little mentoring involved in advisement, because the number of choices are very limited. This rigid curriculum results in a low level of specialization amongst the students, because the curriculum attempts to cover all of the areas of engineering, i.e. just-in-case learning. A more flexible curriculum would promote a higher level of specialization amongst the students. In a curriculum that embraces niche construction the individual student's abilities and interests will guide the courses that they take and each student can become a specialist in a variety of areas. A rigid curriculum imposes uniformity on the students, as opposed to a flexible curriculum that encourages each student to reach their highest potential (encouraging diversity).

A complete restructuring of this curriculum is not likely within the within the traditional engineering department; however a few changes can be implemented so that it is following the concepts of niche construction. A curriculum committee has been meeting regularly this semester to address the current curriculum and to suggest changes. To encourage the concept of niche construction two committee members have pushed for a set of open elective courses. The decision has been made to have a set of predetermined (by the student and advisor) elective courses that are not restricted to a prescribed list of courses. For example, a student interested in Spanish or art could take their respective elective courses in those areas, while a student that is interested only in engineering courses can create a set of elective courses that consist of engineering ones. Simply adding this option to an existing curriculum allows the students to create their own niche to a small degree. Allowing the students more opportunities to select their courses for their degree would create a greater opportunity for niche construction. While this is a small change in the curriculum, it begins to allow opportunities for affecting their environment. Future revisions of the curriculum can integrate niche construction to a larger degree resulting in more opportunities for students to affect their environment.

The new engineering curriculum will integrate concepts of niche construction to a deeper level. One of the key goals of this program is to develop long term, multifaceted projects. The students will be given flexibility to select the courses they take, based on their project teams needs. Thus, a student will become the "resident expert" for their project team in their chosen optional topics. This requires additional work on the part of the faculty advisor and student; however, it will create greater latitude for students to chart their own course of study in pursuit of their engineering degree. This will give the students the ability to create their own niche

within the engineering program. The students will be encouraged to leverage the strength of design team cohorts by allowing design teams to parse out and choose courses among individual team members that can be brought to bear on the project at-hand which will in turn necessitate peer-to-peer instruction and broaden student exposure and knowledge base. A mechanism will also be in place for the students to request specific courses or seminars that are not currently available and would be beneficial to their expertise on the project team.

The entire educational experience within the new engineering curricula will also embrace the concepts of niche construction. The educational experience includes courses, extracurricular activities, work experiences, research experiences, and a professional development experience. During advisement the students will be required to take a macro-level view of their progress towards their personal vision. This will involve the students taking a continuous improvement strategy to their development as an engineer (plan, do, check, and act) (See Figure 3 for a sample template). The "plan" portion of the cycle will involve each student discussing their overall vision and more specific objectives. The "do" portion will involve a discussion of what they have done and are currently doing to reach their personal vision and objectives. The "check" portion of the cycle will involve the students determining whether what they have done and are doing is in alignment with their vision. The students will then need to perform a self-assessment to determine what they need to change about what they are doing so that they will be progressing towards their personal vision (the "act" portion). This cycle will be repeated at least once with the help of a mentor during each semester. The students will be encouraged to use this tool between advisement appointments to ensure that they are moving towards their personal vision.

Continuous Improvement Strategy (CIS)

Personal Information

(Name, Address, Phone Number, Email, Year in School (1st semester Freshman, 2nd semester Junior,…)

Plan

Vision:

Objective:

Do

Have done: (Include courses, professional development experiences, and extracurricular activities. Include personal skills and attributes that will help you reach your objective. For the first semester only, list information from high school.)

Currently doing: (Include courses, professional development experiences, and extracurricular activities. Include personal skills and attributes that will help you reach your objective).

Check

Is what you have done and what you are doing in line with your vision and objectives?

If not, where should you be now?

Act

Actions for necessary improvement, where you are going: (Include courses, professional development experiences, and extracurricular activities. Include necessary personal skills and attributes to meet your objective).

FIGURE 3. Continuous Improvement Strategy Template

Potential Tensions

Potential tensions will inevitably develop when implementing a program that embraces niche construction. From the perspective of the instructor or advisor there will be a loss of control. In giving the students control of their environment they may make some choices that the instructor or advisor may not believe will be positive for the student. For example, signing up for some art courses may be a very positive experience for an engineering student interested in design, but is different from what many engineering instructors believe is an appropriate, useful course for an engineering major. There also may be a problem of student indecision. Some students would much prefer an advisor to tell them exactly which courses to take. More choices can lead to more confusion for the student and the instructor. There also will be a possible tension because of the student and faculty motivation. All of the participants in the system will be asked to spend more time developing and thinking about an appropriate curriculum. The instructor and student will need to be committed to spending more time doing things that were done very quickly previously with a prescribed curriculum. Finally, there could be a very fundamental tension when instructors and students are faced with the realization that an education is more holistic (inclusive) than a set of courses.

Conclusion

Niche construction is the phenomena in which organisms change their environment in order to be successful with their current strengths (abilities and interests). By having students create a curriculum (with the required fundamental engineering courses); they will be able to change their environment to capitalize on their abilities and interests, and to reach their highest potential. Their learning environment is made up of courses, a professional development experience, and extracurricular activities.

Currently the engineering educational program can be described as a mass production approach, i.e. every student's unique abilities are suppressed in an attempt to graduate students with the same abilities. The experts agree that this mass production approach is not ideal for current or future educational programs (Bar-Yam, 2004, 182-197; Covey, 2004, 12-24; Hock, 1999, 55-57; Pink, 2005, 48-51; Senge et al., 2000, 27-58). Concerns expressed within the engineering education literature indicate that the current engineering educational program needs to be changed to meet the changing needs of our society. The proposed Engineering Educational Niche Program will address these concerns by changing the existing structure of engineering educational programs so that the students are more active agents within their environment.

References

Bar-Yam, Y. 2004. *Making Things Work: Solving Complex Problems in a Complex World*. Cambridge: Knowledge Press.

Bateson, G. 1979. *Mind and Nature: A Necessary Unity*. New York: E.P. Dutton.

Bertallanfy, L.v. 1969. *General System Theory: Foundations, Development, Applications*. New York: George Braziller.

Covey, S.R. 2004. *The 8th Habit: From Effectiveness to Greatness*. New York: Free Press.

Gattie D.K., N.N. Kellam, & H.J. Turk. 2007. Informing ecological engineering through ecological network analysis, ecological modelling, and concepts of systems and engineering ecology. *International Journal on Ecological Modelling and Systems Ecology*. In press.

Hock, D. 1999. *Birth of the Chaordic Age*. San Francisco: Berrett-Kohler Publishers.

Odling-Smee, F.J., Laland, K.N., & Feldman, M.W. 2003. *Niche Construction: The Neglected Process in Evolution*. Monographs in Population Biology. 37. Princeton: Princeton University Press.

Pink, D. 2005. *A Whole New Mind*. New York: Riverhead Books.

Radford, M. *Prediction, Control and the Challenge to Complexity Science.* Paper presented at the annual Complex Systems and Education Research Conference, Vancouver, February 2007.

Senge, P., N. Cambron-McCabe, T. Lucas, B. Smith, J. Dutton, and A. Kleiner. 2000. *Schools that Learn: A Fifth Discipline Fieldbook for Educators, Parents, and Everyone Who Cares about Education*. New York: Doubleday.