AC 2008-1347: THE FOUR-DOMAIN DEVELOPMENT DIAGRAM: A TOOL FOR DESIGNING DEVELOPMENT-CENTERED TEACHING

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The Four-Domain Development Diagram: A tool for designing development-centered teaching

Abstract

Research in education has brought to light the complexity of the learning process, demonstrating that students' development is influenced by a myriad of cultural and social factors, as well as the environment in which learning takes place. Engineering curricula, however, are primarily focused on teaching content knowledge, often resulting in a gap between what is taught and what is learned. We propose that shifting some of the focus onto the *process* of learning that occurs within the student and leveraging multiple known connections from educational psychology can result in more effective engineering education. Here we define “effective” engineering education as that which leads to greater retention of knowledge, accelerated skills development, and enhanced motivation for life-long learning. We have developed a curriculum design tool to facilitate this shift. It is a diagram that makes explicit the connections between properties of the "learning environment" or "cognitive activity" and the development occurring within the student. The Four-Domain Development Diagram, a synthesis of known empirical relationships in the learning literature, enables a faculty member to take a systems approach while designing learning activities. For example, it is known that several factors increase the construct of intrinsic motivation (a key ingredient in self-directed learning) such as students' valuation of the material being learned, autonomy in the learning process, a sense of relatedness in the learning environment and experiencing mastery. Unlike other models of learning which focus on the independent influence of one or two constructs, such as student *interest* or *choice,* our diagram enables one to design the learning experience to utilize the multiple natural known-relationships within the learner’s development to promote a greater internal drive for learning.

Over the course of a three-year period, three cohorts (totaling ~120 students) have participated in learning experiences which have been designed according to the relationships in the Four-Domain Development Diagram. Engineering students in "learning experiences" designed according to the diagram report significantly higher levels of interaction with peers as learning collaborators, greater use of integrative cognitive strategies during self-directed learning and a higher degree of moral reasoning than comparison groups (these results are being published elsewhere). While it is not possible to establish a definitive cause-effect relationship, the results provide encouraging signs that the diagram can be useful as a design guide for simultaneously leveraging natural causal relationships leading to students' development along cognitive, affective, psychomotor and social domains. In this paper, we present the model and its key theoretical and empirical underpinnings. We also provide examples of how it can been used.

Introduction

Many blue-ribbon reports outline the complexities of the 21st century and articulate the new skill set that is required for graduates in science and technical fields[1,2]. In addition to mastery of their discipline, they call for the ability to function on multidisciplinary teams, think holistically, and engage in self-directed learning. Leah Jamisen, Dean of Purdue's college of engineering, also calls for "reflection,"[3] a critical practice of moral and ethical development[4]. While many of these skills have appeared to some extent in engineering accreditation criteria, engineering programs traditionally focus on the science and engineering content in their curricula, rather than developing and measuring skills like “life-long learning”. In an effort to intentionally strengthen students’ development in these other areas, we turned to the research literature to discern how the various constructs such as moral development or self-directed learning, are linked to controllable aspects of the learning environment. Ideally, an engineering educator would have an equation that described how the variables within the classroom (e.g., mode of teaching, classroom environment, assignments) affected students’ development. What we created from synthesizing the many interdependent relationships was a diagram that shows the causal relationships between the aspects of the classroom environment and students’ development. In this paper, we present the model and its key theoretical and empirical underpinnings. We also provide examples of how it can be used.

The central drive for learning: the learner’s engine

To explain the model, we first consider that our goal as engineering educators is to promote the whole development of our students. If we were to conceptualize the student as a developmental map, it may look something like Figure 1 (many of the model elements are omitted from this diagram for clarity). This shows the students’ developmental “space” as consisting of four developmental domains: cognitive, social, affective and psychomotor. In this diagram, we place the cognitive and psychomotor on the left to indicate that these are left-brain associated. The social and affective domains are placed on the right to indicate their right-brain association. Of course, development within any of these domains is intertwined with the other. For example, one cannot develop socially without the ability to think (cognitive) and feel (affective). However, the diagram serves as a way of viewing the learner’s developmental space.

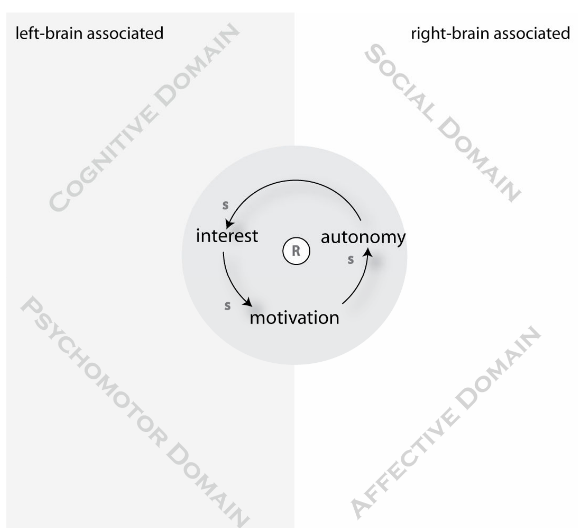

Figure 1. Students’ development space and internal drive for learning.

At the center of the diagram resides what we refer to as the students' *internal drive* for learning/development. It is well-recognized that the learning process is constructive, requiring an active role by the learner. That is, while teachers can provide information, structure activities, and illuminate concepts, learners must initiate, monitor and regulate the process of incorporating the ideas into their mental models. Pintrich referred to this "active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate and control their cognition, motivation and behavior, guided and constrained by their goals and the contextual features in the environment" as *self-regulated learning* or *self-regulation*[5]. Self-regulated learning consists of three components: 1) metacognitive strategies (planning, monitoring and modifying one's cognitive development); 2) time-management on academics tasks; 3) employment of strategies to learn and understand material[6]. An attribute of self-regulated learning is one's autonomy, or freedom to act independently. Because learning occurs *within* the learner through interaction with environmental elements (e.g., socil interaction, learning tools), all learning is controlled by the learner, to some extent. That is, one's development requires that the learner choose to engage in learning. Engaging may take on many forms, ranging from passive forms (e.g., observing) to active forms (e.g., practicing). In essence, there must be some internal drive for the learner to engage in learning process. The central circle in the diagram is a conceptual representation of this drive. Within it are the constructs that fuel its strength, *interest* (in what is being learned), *motivation* (more specifically, an internal or *intrinsic* motivation), and *autonomy.* The work of many researchers shows that these aspects mutually reinforce one another[7-11], indicated by the "R" in the center "Reinforcing" loop. In the diagram, the reinforcing relationship is depicted by arrows between, for example, *interest* and [intrinsic] *motivation*, with the small "s" near the arrow head indicating that changes in one cause changes in the *same* direction in the other. So, a student's internal drive for learning can be strengthened by enhancing any one of the three internal constructs. As an example, if a student is more interested in a topic, they have a greater motivation to learn which has been shown to lead to a greater exercise of autonomous actions to engage in learning[12]. These relationships work in the reverse direction as well. For example, someone who is not interested in what they are learning will also exhibit a lower motivation.

Engaging the internal drive for development

Figure 1 lays out the conceptual idea of the learner as one with an internal drive for learning within the context of their own development (i.e., the four domains). The internal drive can be regulated through elements of the learning experience. But how does one convert this drive to development within the domains? The Constructivist theory discussed above indicates that learning requires an action on the part of the learner to take place—they must initiate their own development. This is represented in the diagram as shown in Figure 2. Here, the arrow emerging from the center circle (in the 6 o'clock position) goes to "engagement/active learning," indicating that the learner must choose to engage for development to take place. Engagement is placed on the center between left- and right- brained activities, to indicate that learning is inseparable from the social contexts in which it occurs[13]. In Figure 2, "mastery" is placed at the intersection of cognitive and psychomotor development and "moral and ethical development" at the intersection of social and affective domains. When viewing the diagram, developmentally advancing in mastery or moral development would equate to moving along an axis centered on the construct and coming out of the plane of the paper toward the viewer. The highest order of development for *mastery* would be self-directed learning or cognitive autonomy, akin to the construct that engineering educators call “life long learning.” For *moral and ethical development*, a higher order of development would be characterized in Kohlberg’s model[14] as *principled conscience*, where the individual is able to put aside his own needs for the benefit of anonymous others. Kohlberg proposed that moral development occurs through a process where an individual must actively resolve a conflict between their personal values and a conflicting broader context and is socially mediated.

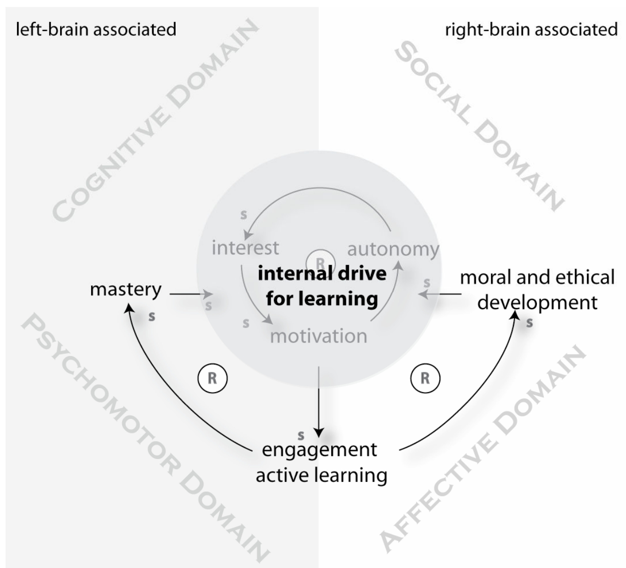

Figure 2. Mechanism of converting internal drive for learning to development.

Note that the internal drive is represented as one entity from which one acts to engage in learning. Likewise, when one experiences mastery after engaging[6,15], their internal drive increases[9] as indicated by the arrow connecting mastery and the internal drive. Another reinforcing loop is created. Again, this loop can run in an unintended direction: when a student feels defeated after engaging in a learning activity, their sense of mastery goes down, subsequently lowering their internal drive for learning that particular skill.

Other factors in the learning environment

Figure 3 represents other factors in the learning environment that have been shown to influence students’ development. This diagram illustrates how a student’s sense of belonging and safety in the learning environment (*relatedness*) is tied to the internal drive for learning. This link is based on research showing the importance of *relatedness* to one’s drive for learning[16]. Once again, research shows that it is possible to deflate a learner’s internal drive for learning by creating environments that decrease students’ sense of *relatedness*[17].

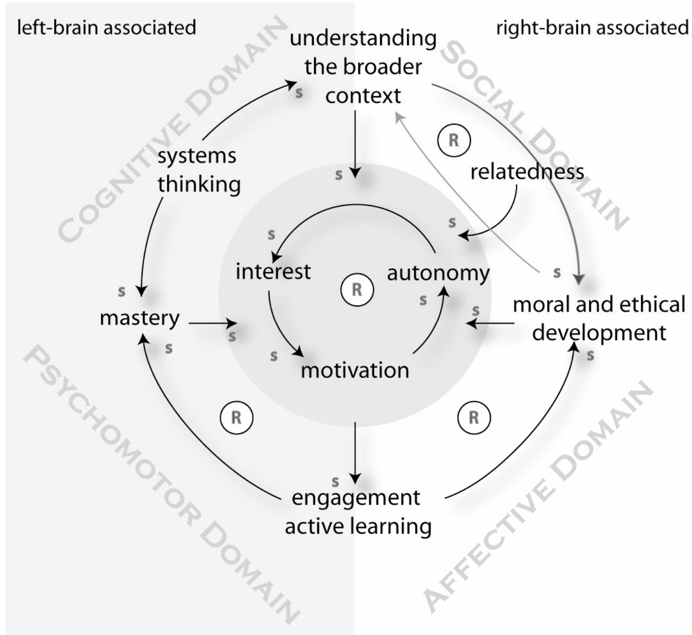

Figure 3. The Four Domain Development Diagram.

In Figure 3, *understanding the broader context* is also shown to influence one's internal drive for learning. This construct is placed in at the intersection of the left- and right-brain associations, as it draws on both. In its simplest sense, understanding the broader context equates to knowing the relevance of what one is learning. The work of Assor shows that this is critical to one's motivation to learn[11]. However, there is also evidence that understanding broader contextual issues is of great value and interest to women[18] and young women choosing science careers[19]. The relationship of *systems thinking* on the diagram is one that we are studying.

Using the diagram in course design

Although not exhaustive, the model provides opportunities to design learning experiences to strategically target students' development. To use the model in course design, an instructor should first identify the targeted type of development. At the simplest level, suppose an instructor would like to increase student's *internal drive for learning* the course material. In reference to the 4DDD, the targeted outcome of the instructor is to strengthen the center shaded element. As shown in Figure 3, several factors have been shown to influence the strength of this central element. For example, by increasing students' *understanding* [of] *the broader context*, the instructor can increase students' *internal drive for learning*. That is, showing how what is learned is relevant to their goals, one can increase the *internal drive* to learn. Because increases in the *internal drive* also fuel increases in *engagement*, showing the student the broader context is also likely to increase their engagement in the learning process and subsequently *mastery* of the material. By simply ensuring that the broader reason for learning the material is clear, there is likely to be an improvement in *mastery*, due to the natural relationships between the constructs. Conversely, robbing students of this understanding diminishes students' drive for learning and subsequent mastery.

We believe that the usefulness of the model comes from not altering one element of the learning environment, but through designing learning experiences that strengthen several elements simultaneously. For example, presume the instructor desired to increase the students' *moral and ethical development*. Figure 4 indicates the pathways that lead to *moral and ethical development*. One possible pathway may look like the following, in which "↑" indicates the idea of "increasing" a particular construct, while "→" indicates "causes an…" :

↑*systems thinking*→↑*understanding the broader context*→↑*moral and ethical development*

Another path is:

↑*relatedness*→↑*internal drive*→↑*engagement/active learning*→↑*moral and ethical development*

An alternative path is:

↑ *understanding the broader context*→↑*internal drive*→↑*engagement/active learning*→↑*moral …etc.*

or:

↑*autonomy*→↑*interest*→↑*motivation*→↑*engagement/active learning*→↑*moral and ethical development*

The strategy for the instructor would be to design assignments and structure the learning environment to leverage the multiple, natural causal relationships that lead to greater *moral and ethical development*.

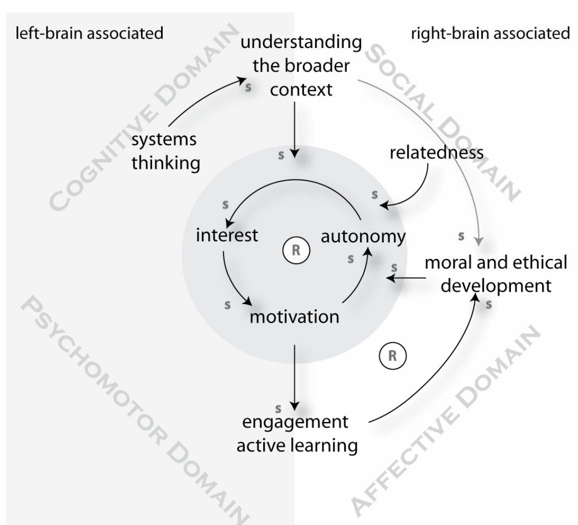

Figure 4. Pathways to moral and ethical development.

For example, these natural, multiple relationships were used in the design of a freshman-level, 1-unit materials engineering course which met for 3 hours per week over the course of a complete academic year (90 total class hours). In essence, the course that we are speaking of made up 6-8.3% of the units taken by this cohort of students during their freshman year. We note that the balance of the curriculum was the usual sequence of freshmen-level communication courses (technical writing, composition, speech), calculus, chemistry, and physics. Some may have also taken courses in computer science and computer-aided drawing. In other words, ~91-94% of their total freshmen year of courses was similar to other engineering programs in the U.S..

During the first of the three-term, freshmen design sequence, students worked in teams of five or six on three projects. The projects required teams to design, build, test, and analyze solar water heaters for fictitious clientele during the first term. During the second and third quarters, students worked on teams of 9-15 to develop a needs assessment, conceptual design, and functional requirements for real, under-served clientele (the second term) and provide an engineering solution that addressed the needs of their clientele (the third term).

At the beginning of the course, students were put into formal teams for the purpose of increasing their sense of *relatedness* (↑*relatedness*→↑*internal drive*), students learned about the engineering profession, problems that engineers must contribute to overcoming (↑*systems thinking*), and the inherent responsibility of future engineers to solve these problems (↑*understanding the broader context*). Reading, studying, and making handwritten copies of the National Society of Professional Engineer's Creed (↑*engagement/active learning*) helped students solidify the concept that the engineering profession is one of service for the benefit of humanity. Students then completed a series of attitude and reflection exercises. The intent of the reflections was to engage them in an activity (↑*active learning*) for the purpose of promoting *moral and ethical development* that helped frame future learning experiences. Reflection activities helped students see themselves as a part of the global community (↑*understanding the broader context*), as well as provide an opportunity to develop communication, self-assessment skills, and moral reasoning. Finally, a documentary on alternative transportation called *Energy: Power Shift* was shown in class to activate a vision of the role students can personally play in contributing to society as engineers. This served the dual purpose of promoting *understanding the broader context*, and initiating *systems thinking* as it helped connect students to concepts that at first seem disconnected (e.g., public policy and engineering design). Equipped with a broad contextual understanding of their responsibility as future engineers, students began working on their solar water heater projects.

The primary goal of the first project was to build a sense of *mastery* and *self-efficacy*. As shown on the 4DDD, *mastery* strengthens the internal drive for learning which feeds *engagement/active learning* (reinforcing loop:↑*mastery*→↑*internal drive*→↑*engagement*→↑*mastery*). Solar water heaters were chosen because they are conceptually simple systems with social, global, and economic implications (again, strengthening the holistic, *systems thinking* ideas). For example, 14-25% of the average U.S. household energy is used to heat water[20, 21]. Concrete experience designing (cognitive) and building (psychomotor) a simple system also empowered students by enabling them to experience early mastery of appropriate challenges. As shown in Figure 4, *mastery* increases the internal drive of students by increasing their *interest*, *motivation*, and *autonomy* to become active participants in their learning process (↑*engagement/active learning*). To summarize, we designed the course with the intent of simultaneously leveraging the many natural causal relationships that interact to result in greater mastery and moral development.

For this group of students, we gathered data on their moral reasoning skills at the beginning of the freshmen year and again at the end of the year to determine the extent to which students' moral development grew. We note that it was not our intention to prove that using the 4DDD relationships are valid, since the relationships come directly out empirical research reported by others. However, we did compare the scores for moral reasoning to those of the national averages for engineers to see if they were similar.

Data was collected from a total of 25 freshmen materials engineering students enrolled in the course (data from a further 18 students could not be used for methodological and statistical reasons). The sample was 92% male, had an average age of 18 years, and was normally distributed across liberal, moderate, and conservative political views. The instrument used to collect moral reasoning scores was the Defining Issues Test, version 2 (DIT-2) developed by James Rest and colleagues[22] and based on Lawrence Kohlberg's theory of cognitive moral development[23]. The survey measures a number of indices related to moral development; however, we focus here on the N2 score – a measure of the extent to which students prioritize post-conventional moral reasoning (i.e., principle-based reasoning) and simultaneously reject the lower forms of moral reasoning based on personal interests. Validity scores for the DIT-2 are consistently strong and are reviewed elsewhere[24]. Specific internal consistency scores for this survey administration were slightly low, but acceptable (Cronbach's alpha = 0.67 – 0.69).

Pre-test data show that the sample reported a mean N2 score of 35.77 (σ=13.71). This compares to a national average for freshmen of 31.05 (σ=14.42)[25]. These values were not significantly different (t=1.71, p>0.01), indicating that the students in this sample were similar to other college freshmen. The sample did report slightly higher moral reasoning scores when compared to other samples of engineering freshmen (N2=28.50, σ=12.87) however[26]. This difference was statistically significant (t=2.52, df=244, p<0.05), and also points out that nationally, engineering students report lower moral reasoning scores than college freshmen generally.

Analysis of the post-test data shows that N2 scores for the sample increased by 22% to 43.62 (σ=11.64). Compared to the pre-test scores, this represents both a significant (t=3.37, df=24, p=0.006) and large (d= 0.62;effect size relative to the standard deviation) increase in moral reasoning. This level of moral reasoning is roughly equivalent to that expected for someone who has already received a professional degree (N2=44.97)[25]. This suggests that the year-long learning experience had a profound impact on the students' moral reasoning. Even more astonishing is the magnitude of the difference between the post-test scores for this sample and national norms for engineering freshmen (d=1.23) and freshmen in general (d=0.96).

These results serve as an indicator that engineering students in this year-long learning experience displayed highly accelerated development relative to their peers nationwide. While it is not possible to discern the exact source of the measured moral growth in the students, it was not our intention to do so. We note that the course constituted about 8% or less of their total academic freshmen experience, with over 90% being similar to general freshmen engineering requirements. For us, this is a hopeful indication that the learning experiences that leveraged the 4DDD causal relationships had a powerful, positive impact on the students' moral development.

Summary

We have created a model of development (the Four-Domain Development Diagram, or 4DDD) based on the synthesis of established learning theories and empirical relationships. This diagram makes clear the causal relationships between several dimensions of the students' development, enabling faculty to strategically alter learning experiences for development. It addresses students' whole development (cognitive, psychomotor, social and affective domains) and proposes causal relationships between the internal drivers of an individual's development, and their ability to convert that drive into mastery of an engineering discipline. The results of this diagram's effectiveness as a learning-activity design tool demonstrate promising evidence that the 4DDD can guide faculty for strategically development of constructs within the cognitive, psychomotor, social and affective domains.

Acknowledgements

This work was supported in part by a grant from the National Science Foundation (EEC#0530760). The views expressed within this article are those of the authors and do not necessarily represent the views of the National Science Foundation.

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