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Exploring using complexity thinking to extend the modelling of student retention in higher education physics and engineering

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2011

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Thesis for the degree of Licentiate of Philosophy in Physics within the specialization Physics Education Research, Uppsala University, 2011.

Thesis papers

Forsman, J., Linder, C., Moll, R., Fraser, D., and Andersson, S. (accepted). A New Approach to Modelling Students' Retention Through an Application of Complexity Thinking. Studies in Higher Education.

Forsman, J., Moll, R. F., Linder, C., and Andersson, S. (2011). The emergence of social and academic networks: An exploratory study of complex structures and dynamics in students' social and academic networks. Paper presented at NARST (National Association for Research in Science Teaching) international conference, 2011 - Global Sustainability and Public Understanding of Science: The Role of Science Education Research in the International Community, Orlando, Florida, USA, April 3 – 6.

Forsman, J., and Andersson, S. (2010), Studenters stödjande nätverk. Poster presented at the NU2010 Dialog för lärande Conference, Stockholm, Sweden, October 13 – 15.

Supporting work

Papers

Enghag, M., Forsman, J., Linder, C., MacKinnon, A., and Moons, E. (in revision). Using a disciplinary discourse lens to explore interactions and communicative approaches used in a typical wave-physics course. International Journal of Science and Mathematics Education.

Chapters in books

Forsman, J., and Andersson, S. (2010). Två teoretiska modeller för studentavhopp från universitetsutbildning. In Johansson, B. (Ed.) Att undervisa med vetenskaplig förankring - i praktiken!: Universitets-pedagogisk utvecklingkonferens: 81 – 90. Uppsala: Universitetstryckeriet.

Forsman, J., Andersson, S., Andersson Chronholm, J., and, Linder, C. (2010). Disciplinära diskurser i naturvetenskap och matematik. In Johansson, B. (Ed.) Att undervisa med vetenskaplig förankring - i praktiken!: Universitetspedagogisk utvecklingkonferens: 41 – 47. Uppsala: Universitetstryckeriet.

Conference posters and proceedings

Andersson, S., Forsman, J., and Elmgren, M. (2011). Studenters upplevelser av första året. Poster presented at the Konferens i universitetspedagogisk utveckling, Uppsala, Sweden, October 6.

Fraser, D., Moll, R., Linder, C., and Forsman, J. (2011). Using complexity theory to develop a new model of student retention. Paper presented at the REES (Research in Engineering Education Symposium) 2011, Madrid, Spain, October 4 – 7.

Forsman, J., Linder, C., Moll, R., and Fraser, D. (2011). Using complexity thinking to develop a new model of student retention. Paper presented at SEFI 2011 (European Society for Engineering Education) Conference, Lisbon, Portugal, September 28 – 30.

Forsman, J., and Andersson, S. (2010). Att arbeta med studentretention. Roundtable discussion at the NU2010 Dialog för lärande Conference, Stockholm, Sweden, October 13 – 15.

Andersson, S., Forsman, J., and Linder, C. (2010). ”Det löser sig under studiernas gång”. Presented at the NU2010 Dialog för lärande Conference, Stockholm, Sweden, October 13 – 15.

Forsman, J. (2010). Using Complexity Thinking and Network Theory when Modeling Higher Education Student Trajectories in Physics and Engineering Physics. Poster presented at the JURE 2010, Connecting Diverse Perspectives on Learning and Instruction Conference, Frankfurt, Germany, July 19 – 22.

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Forsman, J., and Andersson, S. (2009). Studentavhopp: Varför sker det och hur kan det motverkas? Paper presented at the Universitetspedagogisk utvecklingskonferens, Uppsala, Sweden, October 8.

Forsman, J., Andersson, S., Andersson Chronholm, J. and Linder, C. (2009). Disciplinära diskurser i naturvetenskap och matematik. Poster presented at the Universitetspedagogisk utvecklingskonferens, Uppsala, Sweden, October 8.

Enghag, M., Forsman, J., Moons, E., Linder, C., Andersson, S., and Wickman, S. (2009), Students self-evaluations of themselves as disciplinary practitioners. Paper presented at the GIREP-EPEC 2009 (International Research Group on Physics Teaching) Conference, University of Leicester, UK, August 17 – 21.

Contents

1. Introduction

"Figures are the most shocking things in the world.
The prettiest little squiggles of black looked at in the right light
and yet consider the blow they can give you upon the heart."
— H.G. Wells

Introduction

After starting my Ph.D. studies at Uppsala University in 2009, I soon came to know many first-year Master of Science in Engineering Physics, and Bachelor of Science in Physics students. When I started writing this thesis (January of 2011) most of this community of students should have been in their third year of study within their programmes. However, only 30 of the original 93 Master of Science in Engineering Physics students and only four of the original 43 Bachelor of Science in Physics students were still in phase with their programme of study. This is an illustrative example of the main issue driving my research interests – student retention in Higher Education Physics and Engineering.

I also met the work of Brent Davis and Dennis Sumara who have recently pioneered opening up the idea of using complexity thinking as an appropriate powerful education research tool. Their ideas took me on a journey of exploration into the modelling of *student retention*, which I describe in this thesis.

Is better recruitment not the answer?

A general aim of higher education institutions is to “produce” enough scientists and engineers. One of the most typical mindsets brings the response-focus to improving the recruitment of students: more students starting the programmes is taken to be the answer to improve *student retention* and thus the number of graduating students.

Thus, it is common practice for universities to try to "improve" their recruitment strategy. What "improve" means here is to attract more, and hopefully "the right" first-year students, who are more inclined to stay and finish their studies on time. However, such recruitment initiatives have tended to fail to acknowledge, and in certain cases even recognize, that it is "very unlikely that there is another hidden pool of students that we might magically discover if we change or further improve our selection procedures" (Allie et al., 2009: 3).

The United Kingdom, as a European Union example, has recently set up several major initiatives and policies aimed towards recruiting more students to participate in science, engineering and technology education. Smith (2010) reports that there is no strong empirical evidence that these reforms have had any impact on the number of students *choosing* to study in these areas. Furthermore, the percentage of students *completing* these kinds of degrees in the United Kingdom has remained limited (European Commission, 2004).

Against the backdrop of Smith’s (2010) study and the continuing withdrawal of students from their studies, I argue that there is a need to shift the focus from what the universities can do to enhance *student retention* through enhanced recruitment efforts, to what universities can do while the students are enrolled in their university programmes.

Why is student retention research important?

The generalized concern about *student retention* and attrition has led to several well publicized major initiatives. For example, the Carnegie Foundation in the United States announced an initiative early in 2010 to invest 14 million dollars to enhance students' "college readiness" (c.f. Carnegie Foundation for the Advancement of Teaching, 2010). This initiative is being partially driven by a country-wide university failure rate that is more than 50% for students studying engineering (Committee on Science, Engineering, and Public Policy, 2007: 98).

Current initiatives and the decline in "graduation rates" in both the European Union and the United States, especially in science, engineering and technology oriented areas, have created a renewed challenge for higher education institutions to create conditions that are more likely to enhance *student retention* and *progression*. Generally, a major challenge to reform and transformation initiatives is the lack of certainty in their aims and outcomes.

Why does the issue of student retention have particular significance in the areas of physics and engineering?

Most developed nations are currently experiencing a huge increase in demand for well-qualified science, engineering and technology graduates. At the same time there has been a deteriorating interest in careers in science, engineering and technology in these countries (for example, see European Commission, 2004; Committee on Science, Engineering, and Public Policy, 2007). Much of the increased demand is being driven by the need to have science, engineering and technology help inform solutions to the many socio-economic challenges that are increasingly emerging from an ever-growing globalized network of nations.

Internationally, it is not uncommon to find that the percentage of students who either do not manage to successfully complete their degree requirements in science and engineering programmes in the designed time period, or who do not graduate at all in the field, is increasing (cf. OECD, 2009; Committee on Science, Engineering, and Public Policy, 2007). In the category of "graduation rates", Sweden (as a strong modern economy example) is ranked in the middle of the OECD member countries. The percentage of university students that complete the Swedish Master of Science Programme in Engineering (4,5 years) within five years of starting has decreased from 30% to 19% from 1987 – 2004 (see Figure 1.1). This occurred while the number of new entrants to these programmes of study increased by 50% over the past fifteen year period (cf. Statistics Sweden and National Agency for Higher Education, 2003; 2005; 2007; 2009; 2010).

My major critique of the initiatives that are employed to enhance *student retention* is the lack of theoretical strength. This critique can be especially directed at initiatives which are informed by one-dimensionality in their planning and execution, as the process of *student retention* has been acknowledged as being far from straightforward.

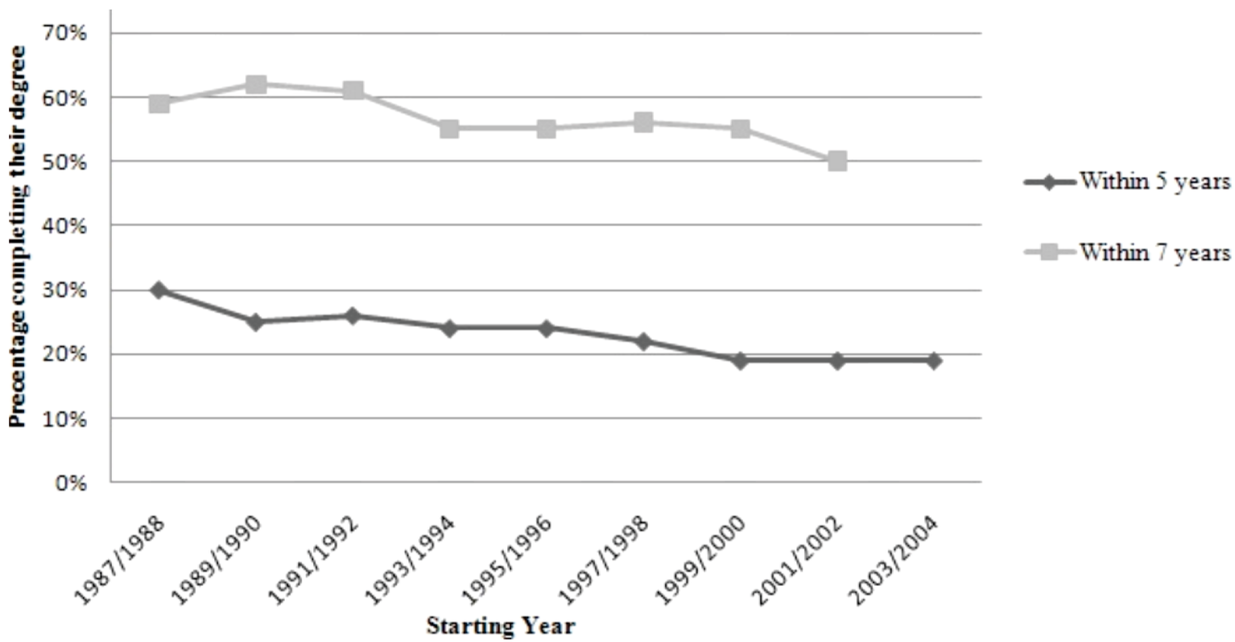

Figure 1.1. Percentage of Master of Science in Engineering students completing their degree within a set time. (Statistics Sweden and National Agency for Higher Education, 2001; 2009)

Research in student retention and complexity thinking

There is no simple road-map for how higher education institutions can better understand and enhance *student retention*. Modelling efforts of *student retention*, with its associated achievement, learning and progression dynamics, in higher education has long been an important area of research. And it can be argued that work in this area is being directed by efforts principally aimed at informing institutional action (Tinto, 2010; Braxton, 2000). The most progressive research in this field has produced modelling systems that are currently widely referred to (c.f. Tinto, 1975; 1982; 1987; 1997; Bean, 1980; 1982) and have, for some time, acknowledged that *student retention* needs to find a better way to take into account the "complex" nature of *student retention*.

The "complex" nature of these modelling efforts have become apparent to many stakeholders in the field (for example, Spady, 1971; Bean, 2005; Cabrera, Nora, and Castañeda, 1993). However, this "complex" nature has not been explicitly incorporated, in a non-linear way, into the modelling efforts. Consequently, the existing modelling systems are easily interpreted in linear ways; something that can be clearly seen in the action plans of many institutions. To address this issue I am, in this thesis, proposing a way of further developing the existing modelling systems by drawing on complexity thinking, which is derived from complexity theory.

Even the notion of "complexity", although apparent, has not been brought to the fore in previous model designs. For example, Spady (1971: 38) argues that the formulation of a truly comprehensive model of *student retention* needs a perspective that "regards the decision to leave a particular social system [i.e. studies in higher education] as the result of a complex social process". More recently Bean (2005: 238) has argued that "students' experiences are complex, and their reasons for departure are complex". There are many other examples, see Spady (1970; 1971), Cabrera, Nora, and Castañeda (1993), Yorke and Longden (2004), Barnett (2007), the collection of articles in Braxton (2000), and Tinto (2010).

Like the notion of complexity, social networks have been present in the background in the development of theoretical models used to understand *student retention*, especially in the work of Tinto (1975; 1982; 1987; 1997). It has been recognized that the field of *student retention* needs to employ "network analysis and/or social mapping of student interaction... [to]...better illuminate the complexity of student involvement" (Tinto, 1997: 619). And it has been known for some time that the structures of social networks are connected to student grade achievement (for example, see Thomas, 2000; Sacerdote, 2001; Rizzuto, LeDoux, and Hatala, 2009).

The theoretical and empirical work that I am reporting on in this thesis reflects my exploration into how complexity thinking could be used in the modelling of *student retention*, building on previous theoretical and empirical work such as the Student Integration Model (Tinto, 1975; 1982; 1987; 1997) and The Student Attrition Model (Bean, 1980; 1982).

Research question

This thesis is situated in physics education research, and its focus is *student retention* in Higher Education Engineering and Physics. The three papers that underpin this thesis constitute the case that I am making that the "complex nature" of *student retention* can be fruitfully modelled using complexity thinking. The data and analysis that I refer to in the thesis are purposely limited as their function at this stage in my work is principally to provide an illustrative base for my research question:

In order to produce a stronger and more effective grounding, how can complexity thinking[1] *be used to develop informative modelling of student retention for the Higher Education Physics and Engineering context?*

One of the primary aims of this thesis is to provide illustrative examples using complexity thinking to answer the research question. I have set out to do that using the following three research themes:

- Complexity thinking having the ability to incorporate previous constructs of student retention research.
- Analytical constructs of complexity thinking being applied to varied sets of data to construct student retention models by taking into account different levels of analysis (illustrated in Paper I, Paper II and Paper III).
- Complexity thinking providing the possibility for further insights into the "complex[2]" system of student retention for students in Higher Education Physics and Engineering.

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[1] Thinking that is derived from complexity theory.

[2] Complexity should not be seen as a synonym for "complicated", but rather as a kind of "generative metaphor" (Schön, 1983) that extends a characterization of "a complex unity that is capable of adapting itself to the sorts of new and diverse circumstances that an active agent is likely to encounter in a dynamic world" (Davis and Sumara, 2006: 14).

Outline of the thesis

To provide the necessary background for the research themes previously described, in Chapter Two I begin by providing a brief, but thorough, overview of what constitutes physics education research. This is followed by an overview of student retention research that gives particular attention to the Student Integration Model (Tinto, 1975; 1982; 1987; 1997) and the Student Attrition Model (Bean, 1980; 1982). I then go on to describe the essentials of complexity thinking in relation to my thesis work, and how these essentials are, in turn, related to network theory.

In Chapter Three, I use results from my three thesis papers to exemplify the use of complexity thinking. These studies show how the attitudes and experiences of students in higher education could be viewed as networked and nested, how the social and academic networks of students' interactions can be modelled and explored, and how the structure and dynamics of supportive networks can be modelled.

In Chapter Four, I provide examples of how an educational complexity thinking perspective can provide powerful insights for universities who want to formulate institutional action to achieve an educational environment that optimizes enhanced *student retention*.

In Chapter Five, I discuss possible future directions for my research project, and the critical concerns that my further work needs to take into account.

Similar theoretical, analytical and methodological descriptions also appear in my attached papers (Papers I-III). Such duplication is purposeful; it is done to constitute a thesis that can stand on its own, while at the same time being anchored in my research outputs.

2. Literature review

"Human history becomes more and more a race between education and catastrophe." – H.G. Wells

What is Physics Education Research?

Introduction

This thesis is situated in Physics Education Research, which is commonly referred to as "PER". PER aims to further understandings of learning and teaching within contexts of physics, astronomy and related engineering educational contexts. Thus, it is principally situated in higher education. As such, PER has become well established internationally as being a legitimate research programme within university schools of physics and departments of physics and astronomy. It is a field of study that is particularly well established across the USA. Here, Lillian McDermott and her research group at the University of Washington and Edward Redish and his group at the University of Maryland are widely credited with the epistemic foundations that legitimized PER as a discipline-based education research endeavour whose appropriate "home" is within Departments of Physics, and Physics and

Astronomy. The following statement that was adopted by the American Physical Society in May 1999 well captures the spirit of this legitimation:

"In recent years, physics education research has emerged as a topic of research within physics departments. This type of research is pursued in physics departments at several leading graduate and research institutions, it has attracted funding from major governmental agencies, it is both objective and experimental, it is developing and has developed publication and dissemination mechanisms, and Ph.D. students trained in the area are recruited to establish new programs. Physics education research can and should be subject to the same criteria for evaluation (papers published, grants, etc.) as research in other fields of physics. The outcome of this research will improve the methodology of teaching and teaching evaluation. The APS applauds and supports the acceptance in physics departments of research in physics education. Much of the work done in this field is very specific to the teaching of physics and deals with the unique needs and demands of particular physics courses and the appropriate use of technology in those courses. The successful adaptation of physics education research to improve the state of teaching in any physics department requires close contact between the physics education researchers and the more traditional researchers who are also teachers. The APS recognizes that the success and usefulness of physics education research is greatly enhanced by its presence in the physics department."(Downloaded from http://www.aps.org/ 6 February, 2011)

PER also has a section in the highly regarded physics research journal, Physics Review, as one of its special topics – see http://prst-per.aps.org/

There are currently more than 80 PER groups across the world; around 50 of them are in the US and 25 of them in Europe. Sweden has one PER group, which is located at Uppsala University. These groups are conducting research that offers both diversity and depth, as illustrated in Table 1.

University of Maryland	Exploring students difficulties in applying mathematics in physics Improving students' mathematical sense-making in engineering. Professional development of teachers using an inquiry based approach
University of Colorado	Exploring the use of new technology in advanced physics courses Improving learning through simulations Research of students attitudes and beliefs and how it relates to their learning
Harvard University	Research into interactive engagement teaching methods Gender issues in introductory physics courses The role of classroom demonstration in physics education
University of Kansas	Investigating how students' problem solving expertise transfers between mathematics, physics, and engineering Research into web tutoring
University of Washington	Research on the ability of students to carry out the reasoning needed to interpret simple phenomena and ability to formulate solutions to both qualitative and quantitative problems Research tested curriculum and teaching practice tools and materials aimed at addressing research-identified difficulties in learning physics
Uppsala University	Theoretical development of the phenomenographic perspective on learning Linking complexity research and related theories to the field of teaching and learning in physics and engineering Exploring the role and function of representations in disciplinary knowledge construction

Table 1: An illustrative selection of leading PER groups showing examples of their recent research interests.

Brief historical overview

The need for research in the area of physics education emerged in the 1950's, when the enrolment and *student retention* in university physics courses was seen to be on a worrying decline, particularly in the United States. The concerns in this area are also linked to the successful launching of the Soviet Sputnik, which led to extensive initiatives in the United States to reform science education. These initiatives fell under the controlling influence of many prominent physicists and they profoundly changed science education in all levels of schooling. A university level interest was primarily situated in the first year of university education. PER, as a research activity in physics departments started studying the challenges that students had with learning physics and how resources and curriculum design could be used to overcome these challenges (cf. McDermott, 1984). Two papers written by Trowbridge and McDermott (1980; 1981) that deal with challenges in learning about velocity and acceleration are widely recognized as representing the start of contemporary PER work.

One of the most extensively used instruments to measure learning in the field of physics is the force concept inventory, the FCI (Hestenes, Wells, and Swackhammer, 1992). This inventory has been widely taken as an effective tool to measure conceptual understanding and has been used extensively to compare learning outcomes pre and post formal instruction. Originally many physics teachers considered the FCI questions to be "easy" and hence were rather surprised when it turned out that a significant number of their students, post-teaching, could not answer many parts of the inventory correctly. Eric Mazur from Harvard University was one of these, and, as a consequence, he went on to develop a now widely used approach known as peer instruction (Mazur, 1997). This approach emphasized highly interactive peer-to-peer and student-teacher activity in a way that yielded significant gains in learning outcomes (for example, see Hake, 1998). The educational process involves engaging students during class using an electronic device known as a "clicker" that records students' choices (for example, see Wieman and Perkins, 2005) to promote peer-to-peer interaction. In a historically significant article, Hake (1998) presented evidence from 6000 students that an *interactive engagement approach* to teaching and learning (Mazur, 1997) had the possibility of dramatically improving student learning, as measured by the FCI.

The work framed by the FCI led to rapid methodological growth and theoretical development in the PER community. Much of the initial framing for investigating challenges in learning physics was couched in terms of *prior knowledge* and *student misconceptions*. Later this framing started to include how students worked with what they knew, for example the modelling of naïve and expert problem solving (for example, see Larkin et al., 1980) and the notion of *phenomenological primitives, p-prims*, (cf. DiSessa, 1993). This growing theoretical base was then used to make strong links to theoretical modelling that was taking place in related research areas such as science education, cognitive science and psychology, in particular, regarding the influence of preconceptions, alternative conceptions, conceptual change and forms of constructivism on learning (for example, see Redish, 2003). This led to powerful foundational connections being empirically established between problem solving, conceptual understanding, prior knowledge, and the experience of learning (cf. Redish, 2003). Into this milieu, Ausubel 's (1968) modelling of meaningful learning, advance organizers, and scaffolding, also began to influence the way curriculum design and teaching practice was thought about. An excellent example of the constitution of research, theory and informed practice can be found in McDermott, Shaffer, and the Physics Education Group at University of Washington's (2002) tutorial design and practice.

Theoretical debate also started to grow in the field. For example, diSessa and Marton debated the epistemological basis of p-prims in a special edition of *Cognition and Instruction*; constructivism (cf. Driver and Erickson, 1983) was linked to p-prims (for example, see Hammer, 1996); conceptual change was challenged and refined (for example, see Linder, 1993); and, new modelling of learning began to emerge in the PER and in the broader science education research communities (for example, see Allie et al., 2009).

PER research has increasingly incorporated broader theoretical groundings, for example, epistemological perspectives (for example, see Linder, 1993; Hammer and Elby, 2002), a learning resource perspective (for example, see Hammer, 1996; Redish, 2003) disciplinary discourse perspectives (for example, see Van Heuvelen, 1991; Brookes and Etkina, 2009; Airey and Linder, 2009), multimodal perspectives (for example, see Airey and Linder, 2011), and gender theory perspectives (for example, see Danielsson, 2009). As the significance for theory building grew for PER work, so did research possibilities expand. For example, studies now include the exploration of learning through the following theoretical lenses: *discourse theory* (for example, Andersson and Linder, 2010), *scientific literacy* (for example, Airey and Linder, 2011; DeBoer, 2000), *ethnography* (for example, Gregory, Crawford, and Green, 2001), attitudes towards physics and science (for example, the Colorado Learning Attitudes about Science Survey [Adams, Perkins, Podolefsky, Dubson, Finkelstein, and Wieman, 2006], and the Maryland Physics Expectations Survey [Redish, Saul, and Steinberg, 1998]), and *phenomenography* (for example, Linder and Marshall, 2003).

Widely used examples of how PER has impacted on the approaches to teaching physics, particularly at the introductory level are *Peer Instruction* (Mazur, 1997), *Just-in-time-teaching* (Novak and Gavrin, 1999), *Physics by Inquiry* (McDermott, 1996), research based textbooks (for example see, *Matter and Interactions* and *Electric and Magnetic Interactions* [Chabay, and Sherwood, 1999]), *workshop* or *studio* based physics learning environments (for example, see Laws, 1991; 1997; Wilson, 1994), and *Tutorials in Physics* (McDermott, Shaffer, and the Physics Education Group at the University of Washington, 2002). Such shifting in perspectives on learning, teaching approach and awareness and new research-verified curriculum materials have become one of the scholarly benchmarks of PER.

Using complexity thinking in PER research

Physicists, biologists, computer scientists and sociologists have used complexity theory extensively as an analytic tool. Bringing such a perspective into the grounding of the conceptual framing of an education research project has been characterized and exemplified as "complexity thinking" by Davis and Sumara (for example, 2006). However, in education research such thinking has only recently started to be acknowledged for its explanatory and predictive potential. In the area of PER, Moll has led the field obtaining her PhD in 2009 with work that examined the emotions, science identities, attitudes, motivations and decision making about physics in physics competitions (Moll, 2009). And my thesis builds on her initiative to explore bringing complexity thinking into the conceptual framing of research into *student retention*.

Physics education research and student retention

The *student retention* work done in PER has been limited, but what has been done has both been insightful and interesting in that it has explored important links between physics teaching, the learning environment, and *student retention*. These are briefly summarized below.

The Colorado Learning Attitudes about Science Survey (Adams, Perkins, Podolefsky, Dubson, Finkelstein, and Wieman, 2006) showed that students' attitudes, especially in the area of *personal interest* in physics were connected to students' *course completions*.

The effect of *Peer Instruction* (Mazur, 1997) on *student retention* is a rich ongoing area of current research and new thrusts in the area continue to emerge. Two interesting studies here are how introducing peer instruction increased *student retention* of the introductory physics courses from ~80% to ~95% at John Abbott College, and from ~88% to more than 95% at Harvard University (Lasry, Mazur and Watkins, 2008).

Johannsen (2007) studied the discourse models that physics students used to explain why they decided to leave their physics studies. He found that in his Swedish research context students used a discourse model with the following introspective component: "if students perceive that they have problems in relation to physics... they interpret those problems in terms of their own perceived abilities and social identities" (Johannsen, 2007: 145).

One could argue that PER has acknowledged, at least to some extent, the presence of the *social system* and *academic systems*[1] and their importance for students, through research related to disciplinary discourses (for example, see Airey, 2009).

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[1] See the section on the Student Integration Model in Chapter Two.

Research suggests that students learn what it means to "become" a physicist through the interaction with the disciplinary discourse. For example, Danielsson and Linder (2009) conclude that physics students not only need to learn the content knowledge of physics, but also the rules and expectations of social and academic interaction, to be a considered as a member of the physics community.

Andersson and Linder (2010) identified discourse models for how students describe why they were studying physics and engineering and found an influential connection between the discourse models used, *student retention* and *academic performance*.

Most of the research in *student retention* has taken place outside of physics, and in the next section I provide a literature review of this work.

Student retention research

Introduction

This section begins with very brief descriptions of the Higher Education systems in the United States and Sweden (the United States is included because that is where the bulk of student retention research has taken place). This is followed by an introduction to the relevant student retention constructs used in the thesis, and finally a broad overview of relevant work in *student retention* is given.

The Higher Education system in the United States

Higher education institutions in the USA are legislated for and guided by both the Federal government and by the State that they are situated in. Public institutions get their funding partially from the State and partially from student tuition fees. Currently there are approximately 600 public four-year colleges and universities and 1500 private four-year colleges. Admission to higher education in the USA is usually based on SAT[2] or ACT[3] test scores, but some higher education institutions have much more extensive entrance requirements. For example, other requirements often include essays and letters of recommendation. Typically, students are initially admitted to a university per se and not to a particular department or major, such selections usually take place later in the students' careers (U.S. Department of Education, 2010).

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[2] *Scholastic Aptitude Test.*

[3] *American College Testing.*

The Swedish Higher Education system

The higher education sector in Sweden is legislated for, guided and funded by the Government. The majority of Swedish Higher Education institutions are public authorities. Sweden has approximately 50 Higher Education institutions ranging from research universities to more vocationally oriented institutions. Higher education funding for education is based on the number of registered students and their performance equivalents. (Swedish National Agency for Higher Education, 2008)

Swedish students may apply to take individual courses as well as degree programmes. Students studying a degree programme in areas such as physics and engineering will have course choices that are linked to professional or vocational enhancement. To be admitted to Swedish Higher Education, students need to fulfill general entry requirements and often also programme- or course-specific entry requirements. A selection process can only be instituted if applicants cannot be guaranteed a place due to number and space constraints (Swedish National Agency for Higher Education, 2008). Then the selection process is, in most cases, based on final school grades and the Swedish Scholastic Aptitude Test for Higher Education.

Student retention definition

In the student retention literature the terms *student retention*, *student attrition*, *student persistence*, *student withdrawal*, *student departure* and *student drop out*[4] have all been used. In this thesis I have decided to follow Tinto (2010) and use the constructs of s*tudent retention* to characterize a

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[4] In this thesis, both the terms student *dropout* and *drop out* have been used. The term student dropout is used as a verb, and drop out is used as a noun.

university's ability to retain students, and *student persistence* to characterize the students' aspiration to persist with their studies. However, as my thesis is situated at a Swedish university, I have chosen to focus on the programme level, rather than on the University level.

Much of the early student retention research did not differentiate between a student choosing to leave, or leaving because they failed academically. Nor did the research differentiate between students leaving universities forever, or those that made short breaks in their studies. Without such distinctions, much of the early research on *student retention* arrived at contradictory results (Tinto, 1975).

Tinto (1975) took the construct *student drop out* to mean a student leaving their studies in terms of either voluntary withdrawal or academic dismissal. Such distinctions are very important since they highlight that there are certain formal and informal academic norms that exist within a university culture, which have an impact on the student.

In 1982 Tinto expanded his characterization of *drop out* with *transferrals* (see Figure 2.1). Before this expanded characterization, a student who decides to transfer to another institution could easily be misclassified as *system departure* or *stop-out* (see Figure 2.1). For example, the transfer could be more about moving to another institution that projects a different set of values and norms; ones that are more aligned with the students' own values and norms.

In 1987 Tinto presented a more refined range of categories for *student drop out* that included the essence of his former categories, but took into account different levels of the educational system. *Student drop out* was now divided into three major categories: *institutional departure*, *institutional stop out* and *system departure*. *Institutional departure* is when a student leaves the institution to continue their studies at another institution. *Institutional stop out* is when a student leaves their studies for a short time in order to continue their studies at the same institution. *System departure* is when a student leaves the education system prematurely having not completed their studies. The structure of Tinto's *student departure* definitions (Tinto, 1975; 1982; 1987) is summarized in Figure 2.1.

In the Swedish Higher Education context, complete withdrawal, or a changing of education pathway is difficult to keep track of for retention research purposes. For example, if the student takes study leave to work or do something else, they are required to report their leave of absence to the institution, but this does not always happen.

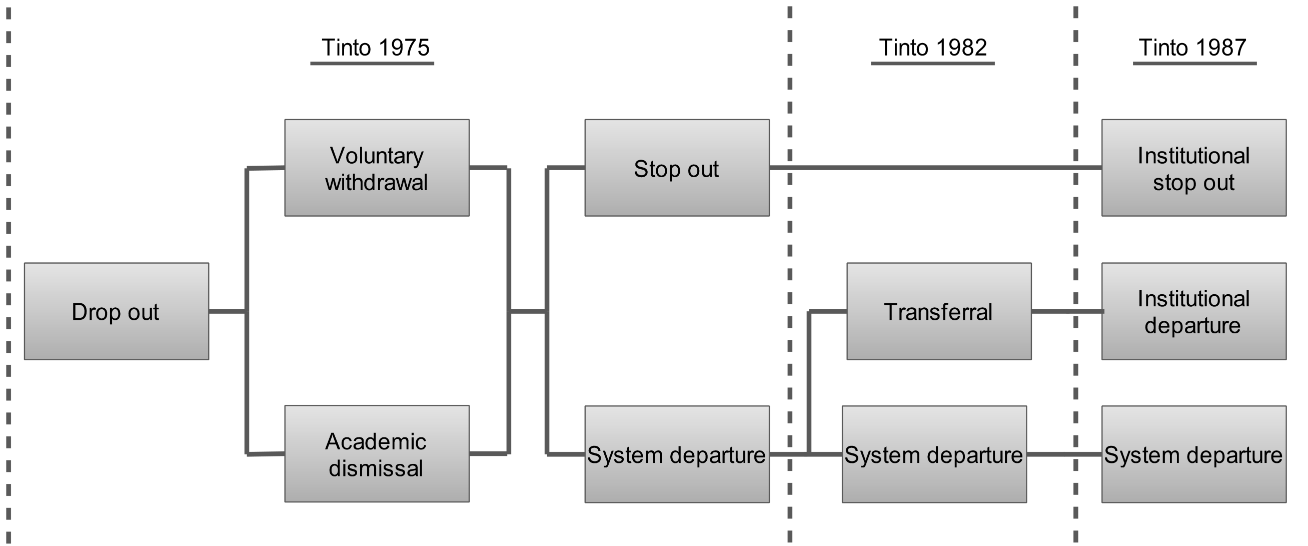

Figure 2.1: Conceptual schemata of Student Departure definitions

Introduction to student retention and persistence research

Research on *student persistence* and *student retention* has shown that the social aspects of participation in higher education play an important role in the formation of students' academic trajectories. Here, the central theoretical modelling for *student persistence* has been done by Tinto – the Student Integration Model (Tinto, 1975; 1982; 1987; 1997) – and by Bean – the Student Attrition Model (Bean, 1980; 1982). Although at one level, significant differences between these models can be identified, the models share similar framing. Thus, in many ways, they can be seen to be largely complementary (Cabrera, Castañeda, Nora, and Hengstler, 1992). A short general historical overview of the development of the field of student retention research is provided next.

General overview[5]

Yorke and Longden (2004) describe how the focus of early studies of *student retention* within higher education was on university structures, for example, libraries, schedules, courses or examination timetables. Thereafter, a shift in systems of modelling *student retention* began towards increasingly incorporating a social integration perspective, influenced largely by the work of Spady (e.g., Spady, 1970; 1971).

According to the social integration perspective, becoming integrated within a *social system* requires learning the norms, value-systems, and beliefs through interactions within the system. The social integration perspective

[5] For consistency and coherence in the main body of the thesis, the description in this section is largely a repeat of the overview given in Paper 1.

played a major role in the development of Spady's theoretical model; students needed to become a part of the social world of the university if the departure rates were to decrease (Spady, 1970; 1971). In this model, social integration is a process that encompasses much of students' everyday life. This includes friendships, family support, the students' feeling of satisfaction and *intellectual development*, and so forth. Spady's model also included student characteristics such as grade performance, family background, and academic potential.

The social integration perspective gained momentum in student retention research through its potential for informing students' and universities' actions towards willingly working to retain more students. The theoretical model of *student retention*, situated in the social integration perspective, grew and Tinto (1975) published an expanded version of Spady's model. Tinto (1975) made a distinction between the *social system* of the university and the *academic system*, and argued that students also need to become academically integrated to persist in their studies. He posited that some interactions that lead to social integration, for example, making friends with fellow students, do not necessarily lead towards integration into the *academic system* of the university. The *academic system*, according to Tinto's (1975) conceptual framework, contains the academic rules, norms and expectations that govern academic interaction within the given institution's context.

During the early 1980s, many researchers in the field started to empirically test Tinto's constructs, and increasingly found that many of them were indeed impacting *student retention*. At this time, Bean (1980), drawing on a psychological background, critiqued Tinto's model for its lack of external factors – for both student and the university such as economy and housing. The point of departure for Bean's (1980) model was that *student attrition* should be seen as analogous to work turn-over in a traditional employment setting. Factors such as social experiences (e.g., how the student experiences the social life of the university), the experience of the quality of the university (e.g., the student perception and experience of the high quality of the university), and family approval (which is external to the student), shape the student's attitudes and behavioural approaches within the university context.

To evaluate Bean's and Tinto's modelling systems, Cabrera, Castañeda, Nora, and Hengstler (1992) surveyed 2453 full-time American first-year students. Their findings indicate that the two *student retention* models have common ground and that they support each other in explanatory value. The questionnaire they designed was made up of 79 items, selected from well validated instruments previously used in the field of *student retention* (for example, see Bean, 1982; Pascarella and Terenzini, 1979).

Later Eaton and Bean (1995) theorized that students' experiences shape their individual behavioural approaches towards university life. This development expanded their earlier model of *student attrition* by adding approach and avoidance behavioural theory. Thus, some students' experiences lead towards avoidance behaviour, and some towards an approach behaviour, both of which affect academic integration and thus the students' intention to leave or stay.

Tinto (1997) then undertook a case study that led him to expand his model by introducing the notion of "internal" and "external" communities that affect *student integration* into the *social system* and the *academic system*s of the university. He asserted that within classrooms there are "internal" *learning communities* where both the *social system* and the *academic system* coexist. Through the concept of *learning communities*, together with the presence of “external” communities, much more could now be achieved with the generation of new constructs that could empower teachers who wanted to improve *student retention* (Tinto, 1997).

After the development of Bean’s and Tinto’s modelling systems very little further work in this area has been reported in the student retention research literature. However, Braxton (2000: 258) has gone on to argue that, due to the wide variations within the empirical trials and findings associated with Tinto’s model, it should be “seriously revised”. Here, Braxton suggests that a new foundation for such modelling needs to be developed. Furthermore, Tinto (2010) himself has recently argued for the need to develop models that aim towards informing the institutional action of universities.

Student Integration Model

This section of Chapter Two is divided into two parts. A brief overview of Tinto's Student Integration Model is given, followed by a more extensive review for readers interested in more detail.

Brief overview

The Student Integration Model (Tinto, 1975; 1982; 1987; 1997) focuses on how students become integrated into academic life through socialisation and cultural assimilation. This theoretical model focuses on trying to understand what integration factors lead students choosing to leave their studies.

In higher education students' choices are based on their interactions with the education environment at their university. The Student Integration Model presents *student departure* as a function of the students' motivation and academic ability and of the *social system* and the *academic system* of the university. In this theoretical framework students' interaction in the university culture impact students' goal commitments and institutional commitments. The Student Integration Model posits that the stronger the commitments the students have, the more they are likely to be persistent in their studies. A theoretical and empirical shortcoming of the model is the lack of structural clarity regarding how these commitments develop throughout students' academic careers.

Background influences on the Student Integration Model

Tinto's theoretical model of *student integration* evolved over time by incorporating empirical findings and new theoretical perspectives. Part of the theoretical framework for the Student Integration Model (Tinto, 1987) is drawn from Durkheim's theory of suicide (Durkheim, 1897). What is pertinent here for modelling *student retention* is that Durkheim's theory proposes that individuals who are not fully integrated into society have a greater possibility of considering suicide. This "lack of social integration" most often takes place when a person finds themselves holding different values to those that underpin the social environment that they find themselves in. The link to Durkheim's theory is that a university community is a strong social environment itself, with its own particular social values (Tinto, 1975).

In 1987 Tinto added economic factors to the Student Integration Model that related to the cost-benefit analysis of the student's educational choice regarding "investment" in alternative educational activities. Depending on how a student perceives the possible benefit of each course and educational choice, they may or may not choose to proceed with their education course or programme.

Tinto (1987) also introduced Van Gennep's (1960) notion of *rites of passage*, which describes a way for an individual to "claim" membership within a new group. These *rites of passage* consist of *separation*, *transition*, and *incorporation*. All three phases describe aspects of changes in a person's membership of groups. *Separation* involves the declining interaction between one's self and the members of the former group with which one was once associated. *Transition* is about how a person starts to interact in new ways with the members of a new group where new membership is being sought. Isolation, training, and sometimes ordeals are used to ensure the breaking away from the former group and to learn the new group's values and associated behaviours. *Incorporation* is about the taking on of new patterns and interactions with the new group, and establishing full membership within the new group.

Thus Tinto (1987), by drawing on structures of suicide, economic notions, and *rites of passage* to community membership, brought attention to the constraints that an institutional environment may be negatively effecting *student retention*. By incorporating these factors, *students' conscious choices* were manifested in the modelling of *student retention*.

The theoretical model of student departure and empirical findings

Tinto's theoretical model, which is shown structurally in Figure 2.2 (Tinto, 1975: 95), illustrates how he proposed students' choices are constituted. Figure 2.2 illustrates, according to the Student Integration Model, the relevant connections between the students' *social system* and the *academic system* of a university, and how these systems influence students' commitments and student's choices.

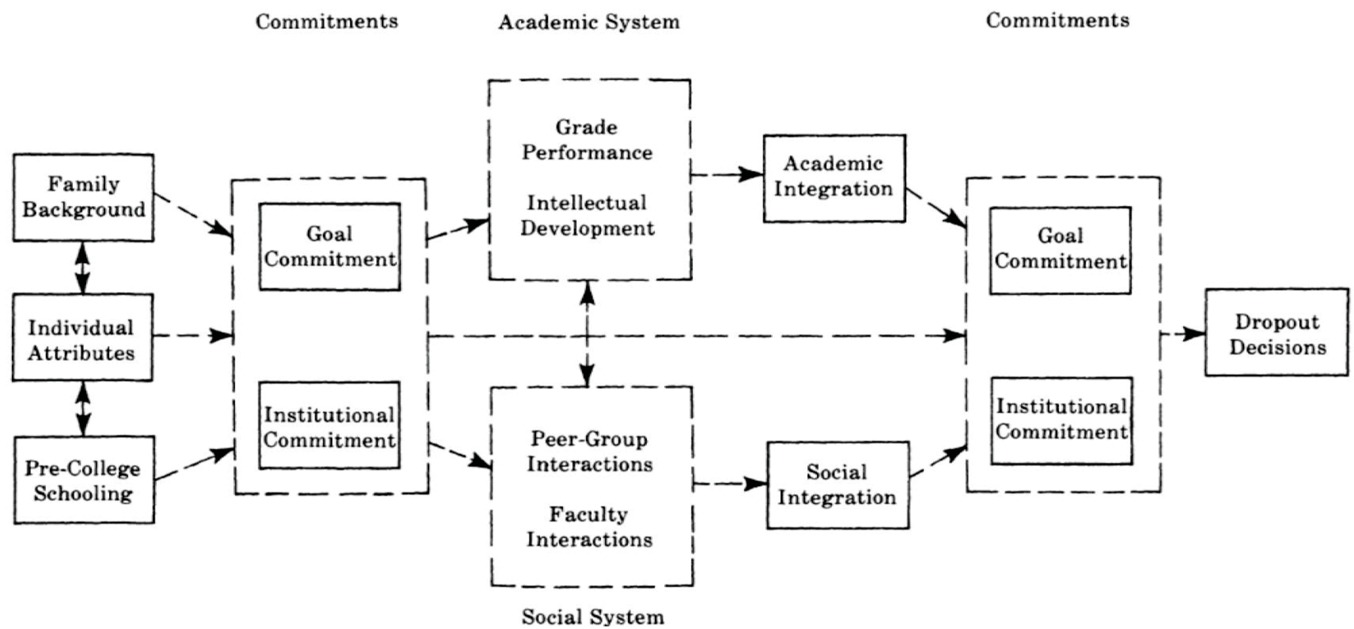

Figure 2.2: Tinto's (1975: 95) conceptual schemata for drop out from university

Individual's characteristics and background

According to Tinto's Student Integration Model, students come to university with critically important individual characteristics and backgrounds. These are critical because they form the basis for future interactions that affect integration into the university system. These characteristics and backgrounds are viewed as mediators for the integration of students into the university's culture (Tinto, 1975; 1982; 1987). The *indirect effects* on *student persistence* have been investigated. One factor, *family background*, which includes items such as *socio-economic status*, and students support from their home environment, has an impact on a student's persistence. *Individual characteristics,* such as *measured ability*, *attitude*, *impulsiveness* and the ability to be flexible when having to deal with changing circumstances, also have their own impact on a student's persistence. A student's past educational experiences – particularly if the student got high marks before studying at the university – has a positive impact on *student persistence* (Tinto, 1975).

Commitments

Tinto's (1975; 1982; 1987) Student Integration Model hypothesizes that both *goal commitment* and *institutional commitment* also play a significant role in *student persistence*. *Goal commitment* depends on how certain students are of what their goals are, and how certain students are that they will achieve these goals. The goal could be measured in terms of educational plans, educational expectations, or career expectations. *Institutional commitment* is dependent on the extent to which students likes or dislikes the institution.

The intellectual congruence between the student and the institution is dependent on the quality and frequency of *student* ↔ *student*, and *student* ↔ *faculty* interactions (Pascarella and Terenzini, 1980; Nora, 1987), by using the Student Integration Model, it is suggested that if a student has a higher level plan (goal commitment), and high institutional commitment, they will be more likely to persist in their education (Tinto, 1975; 1987). In 1997 Terenzini and Pascarella reported finding that students who choose to stay with their studies had a higher interest in their academic programme than those who chose to leave.

Some students have their study goal verbalized, such as wanting to become a physicist or engineer. But many goals that students commit themselves to, are not verbalized, rather they are an intertwined part of the student's life. The uncertainty in the formulation of the goals will not necessarily become a cause for *student departure* and some students even study for a short period in their life without any goal to get their degree (Tinto, 1987).

Students' commitments have been highly intertwined with other constructs of the Student Integration Model. If a university meets the students' expectations of career development, students experience a higher academic and social integration (Braxton, Vesper, and Hossler, 1995). Findings by Nora (1987) show that institutional/goal commitments not only lead to higher retention amongst students, but also lead to a higher degree of academic and social integration. Academic difficulties and social isolation are often a part of students' experiences during the *transition*[6] period to university. This can cause *student departure* or to *stop out*.

Tinto (1987) posited the idea of a *social system* and an *academic system* that can be seen to govern the students' interaction within a university. It is

[6] See section on *Background influences on the Student Integration Model.*

possible to view these systems as composing of some “hidden” values that can only be learned (or adapted to) by a student through interaction with the university systems.

Academic and social systems of the university

Within the students’ ”complex experience” of higher education, the idea of a *social system* and an *academic system* has been proposed (for example, see Spady, 1970; 1971; Tinto, 1975; 1982; 1987; 1997).

“[The] academic and social systems appear as two nested spheres, where the academic occurs within the broader social system that pervades the campus. Such a depiction would more accurately capture the ways ... in which social and academic life are interwoven and the ways in which social communities emerge out of academic activities that take place within the more limited academic sphere of the classroom, a sphere of activities that is necessarily also social in character.” (Tinto, 1997: 619)

The *social system* and the *academic system* are interlinked in a complex way. These systems encompass every part of a student’s social and academic life which is taking place as they are attending a university – making friendships, meeting new people and having social obligations within a social group. Tinto (1975) has argued that individuals not only need to be integrated in one of these systems, but both, to have a chance to continue their studies.

For students to become integrated into the *social system* and the *academic system*, there is a need for the students and institutions to find common ground between their rules, norms, values and expectations that both students and the institution have. Both social and academic integration occur mostly through semi-formal extracurricular activities and interaction with faculty and administrative personnel (Tinto, 1975; 1982; 1987; 1997). However, Terenzini and Pascarella (1980) argue that involvement in extracurricular activities does not have any significant impacts on the students' choice to persist in their studies.

Tinto (1987) states that students need to find some compatible academic group, social group, or some other group with whom to establish membership and establish contacts in order to have a higher likelihood of persisting in their studies. Some students, instead of seeking social membership within the university's *social system*, seek out sub-cultures that exist within a university. Making new contacts and the ability to adjust can be strengthened in one of these groups, communities, or institutions (Tinto, 1987).

Both *student* ↔ *student* and *student* ↔ *faculty* interactions are important for *student persistence* (Terenzini and Pascarella, 1977; 1980; Pascarella and Terenzini, 1980), but *student* ↔ *faculty* interactions seem to be the most important element in the *academic system*. This is especially true when the contacts between students and faculty are outside the formal settings in a classroom (Tinto, 1987). Empirical findings suggest that not only the frequency, but also the quality of the interactions between students and faculty has an impact on *student retention* (Terenzini and Pascarella, 1980).

The lack of *student integration* can be associated with student's isolation; lack of interactions between the student and other students, or the university faculty (Tinto, 1987). Tinto pointed out that students are often forced to adapt to the social and academic setting of the university when they start their studies, and if it fails the student may end up leaving the institution, or the education system all together. Students can also find the setting too alien to adapt to, which can lead to academic dismissal due to unfinished studies.

However, there are ways for institutions to facilitate students' adjustment to university life.

First-year retention is strongly related to an institution's ability to inform students about the institution's expectations and rules, and the fair enforcement of these rules. Also, the students' willingness to be a part of making those rules and other decisions affects the retention of first-year students. This means that assignments and grades need to have clear goals and transparent assessments (Berger and Braxton, 1998).

Academic integration can be measured in terms of a student's grades and *intellectual development* during their years at the university (for example, see Spady, 1970; 1971; and Tinto, 1975; 1987). The *intellectual development* is the development of a student's own personality and self-reflection on their own intellectual integration into, and within, the *academic system*. If the intellectual culture is too alien to the students – making it nearly impossible to interact with – then this can lead to *student departure* (Tinto, 1975).

Intellectual development (Perry and Counsel, 1968) could be argued to be a crucial aim of university studies. *Intellectual development* is an on-going process where students find new ways of interacting within the *social system* and the *academic system*. The *intellectual development* that occurs in the *academic system* is guided by the institution's epistemology; how knowledge claims are made, and what knowledge is valued. The perceived *intellectual developme*nt of a student is argued to be closely connected to the economic notion of cost and benefit. If students feel that the perceived future *intellectual development* has a greater benefit than the cost (time, money and effort) to pass the necessary course, it is more likely that they will persist with their studies (Tinto, 1987).

Intellectual development, as a part of the institution's *social system*, has both an indirect and direct impact on *student persistence*. This is due to *intellectual development* being longitudinal and seen through *student* ↔ *student*, and *student* ↔ *faculty* interaction. When asked to rate the positive effect that people (including faculty members, students etc.) had on their intellectual growth and their personal development, the students who stayed, ranked interactions with faculty highest (Terenzini and Pascarella, 1977). Braxton, Vesper and Hossler (1995) connected *goal commitments* with *intellectual development* in their study of students' expectations as they enrolled at a university. *Intellectual development* was also related to "high goals" in combination with strong institutional commitments. Furthermore, good academic and social integration occurred when the university met students' expectations of academic and *intellectual development*.

Students' non-interactualistic impact factors

The students' financial situation can be an important factor for *student retention*. Tinto (1975; 1982) argues that the financial situation and retention of students is closely linked to the students own view of his situation. If the students' experiences are positive, Tinto[7] theorized that students can accept a greater financial burden than when the experience of university is unsatisfactory. Also, depending on how close the student is to their degree, there can be a difference in how much financial burden a student is willing to accept (Tinto, 1982).

[7] Later on, Cabrera, Nora, and Castañeda (1993) found empirical evidence to support Tinto's claim.

Expanding the model to encompass external factors of the university

With a new expansion of the model – which already involved integration, socialisation, quality of education, university communities, values and norms of a university, student ↔ faculty interaction, personal and institutional goals and commitments, the role of subcultures within the university, financial situations, cost-benefit analysis and much more – another aspect was introduced; classrooms as *learning communities* (Tinto, 1997). This was to have the model encompass more factors from outside the university, and to call attention to what could be done by teachers within the classrooms and courses.

Tinto (1997) conducted a study at the Coordinated Studies Program at the Seattle Central Community College where the students form *learning communities* both in and out of the classroom. A pattern emerged which connected *learning communities*, learning, and *student persistence*. Tinto argued that classrooms involve both the academic and social life of each student and therefore both the *academic system* and the *social system*, which makes classrooms one of the important places for integration to take place. For some students who commute to the university, the classrooms are the only places where they can be integrated into academic life. To be more precise, one could say that the *academic system* and the *social system* "... appears as two nested spheres, where the academc occurs within the broader social system that pervades the campus" (Tinto, 1997: 619). This is a way of saying that these systems are not separate, but are a part of each other in the university system.

How communities of learning affect *student persistence* is summarised under the following three headings: *building supportive peer groups, shared* *learning-bridging the academic-social divide*, and *gaining a voice in the construction of knowledge* (Tinto, 1997: 609).

Building supportive peer groups. Participation in first-year communities of learning enables the formation of small peer groups. These smaller groups make a university seem “smaller” than it is, and, in this way, promote learning for the students involved. If the groups are constructed within the classroom, they often transcend the classrooms themselves to form out-of-class *learning communities*. This positively affects their integration into the new setting of a university (Tinto, 1997).

Shared Learning: Bridging the academic-social divide: One of the important parts of the supportive peer groups is the shared learning. Often there is a strain between the social and academic life of students. One important part of *learning communities* is that the social life and academic life can coexist within the shared *learning community* (Tinto, 1997).

Gaining a voice in the construction of knowledge. Through *learning communities*, students may experience that they need to rethink what they know, become personally involved, and take ownership of their learning. The result of this could be a sense of personal involvement, and a richer learning experience (Tinto, 1997).

In these *learning communities*, learning, and *student persistence* are interlinked in such a way that the formation of a model of *student integration* that also takes into account the earlier findings of both Tinto and others (See Figure 2.3). To see *student persistence* in this way implies that “... choices of curriculum structure and pedagogy invariably shape both learning and persistence on campus...” (Tinto, 1997: 620).

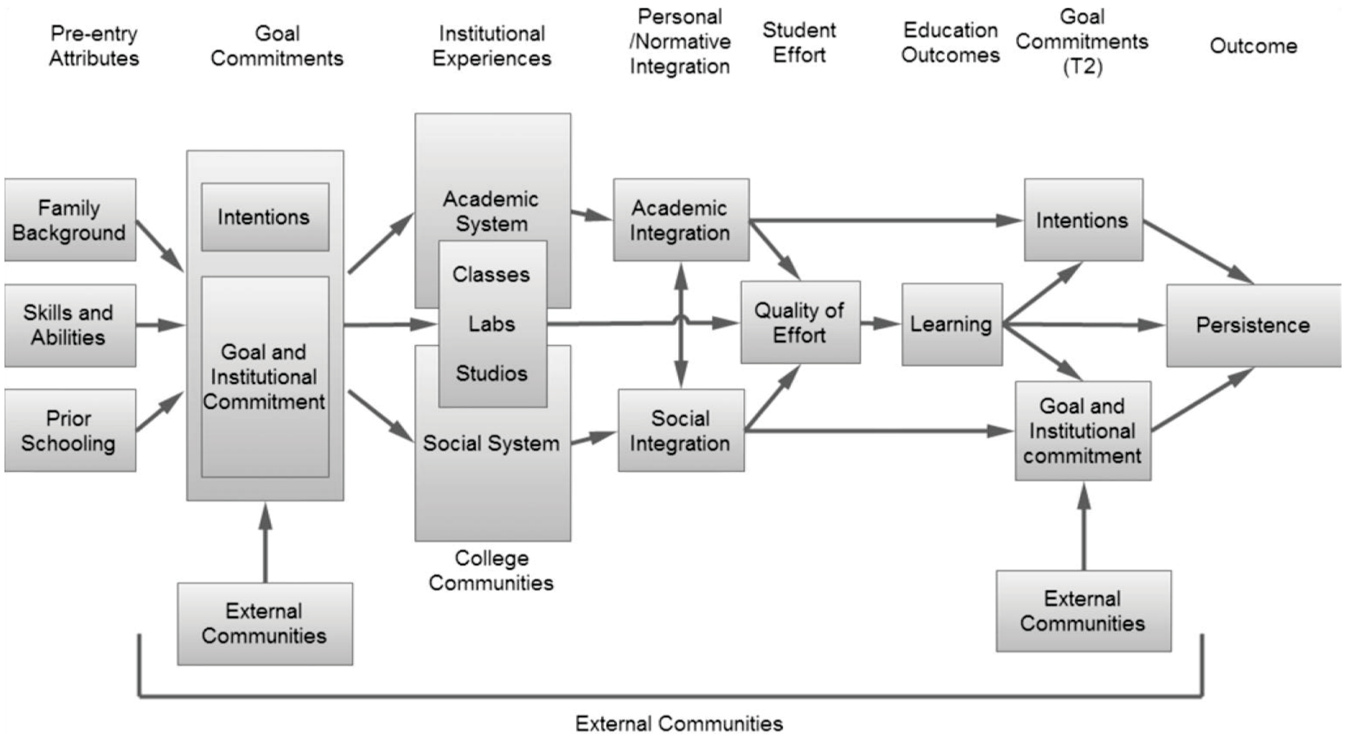

Figure 2.3: Expanded Student Integration Model (Reconstructed from Tinto, 1997: 615)

Student Attrition Model

This section of Chapter Two is divided into two parts. A brief overview of the Student Attrition Model is given, followed by a more extensive review for readers interested in more detail.

Brief overview

In 1980 Bean published his "explanatory" synthetic model of *student retention*. Student beliefs play a major role in the Student Attrition Model, and these are theorized to be formed by student experiences (e.g., courses, social experiences, institutional quality). The basis of the Student Attrition Model is that student beliefs shape students' attitudes, and students' attitudes shape their behavioural intentions and approaches. This model stresses the importance of behavioural intentions (and behavioural approaches) in modelling *student retention*.

In 1995 and 2000 Eaton and Bean extended the model with further refinements (Eaton and Bean, 1995; Bean and Eaton, 2000). They did this by including a schema about how psychological processes affect academic and social integration. In other words, the new modelling included acknowledging that students' beliefs shape students' attitudes, and students' attitudes, in turn, shape their behavioural intentions and approaches. Thus, Eaton and Bean's model can be seen to emphasize the importance of behavioural approaches in the modelling of *student retention*.

The Student Attrition Model in detail

Through a path analysis of a *casual model* of *student attrition*, where *student departure* was taken to be analogous to turn-over in work organizations, Bean (1980) highlights different aspects of the "departure puzzle" than Tinto (1975) did. Through this *turn-over theory*, with the addition of explicit background variables and with translating variables (such as "pay") to their analogue in the education system, Bean (1980) surveyed 1171 first-year university students and mapped out how each of his variables impacted (both direct and indirect) on dropout behaviour.

Bean (1980) began with a large number of variables and by using a stringent statistical analysis he found a set of variables that accounted for the most variance in *drop out*. For females, he found them to be: *institutional commitment* (which is also an important part of Tinto's Student Integration Model), followed by *performance*, *campus organizations*, *practical value*, *opportunity to transfer*, *development*, *routinisation*, *goal commitment*, *satisfaction*, *communication (rules)*, *centralization*, *distributive justice*, and *staff/faculty relationship*.

For males, the variables that had the most impact on student *drop out* were: *institutional commitment*, followed by *satisfaction*, *development*, *routinisation*, *communication (rules)*, and *housing*.

Building on his 1980 study, Bean (1982) found 10 variables that had the most effect on *drop out*. All these variables are also interrelated, but to summarize, the following variables vis-à-vis the total mean effect of each variable, emerged as being critical: *Intent to leave*, *grades*, *opportunity to transfer*, *practical value*, *certainty of choice*, *loyalty*, *family approval, courses*, *student goals*, and *major and students' occupational certainty* (after completing their major) (Bean, 1982).

Extension of Student Attrition Model

While accepting Bean's (1980) model of *student attrition*, Eaton and Bean (Eaton and Bean, 1995; Bean and Eaton, 2000), extended the Student Attrition Model by drawing on psychology theory that deals with coping with stressful situations. According to this theory, the choice of behaviour to cope with a stressful situation is dependent on previous experience of coping behaviours. There are two different paths that could be used to approach the stressful situation, or to avoid it. These two paths have different variations (depending on the experiences of the individual from previous stressful situations).

Eaton and Bean's (1995) Approach and Avoidance Model has four core constructs: *academic approach*, *academic avoidance*, *social approach*, and *social avoidance*. The *academic approach* construct is composed of the positive acts that students employ to enhance academic success; choosing courses, preparing for tests, developing relationships with faculty, and study. The *academic avoidance* construct is composed of the behaviours that students use to avoid, neglect or be passive about academic situations. The *social approach* is composed of the positive acts students employ to enhance social success; making friends and engaging in social activities. The *social avoidance* construct is composed of the acts that students use to withdraw, avoid or otherwise not be a part of socialisations (see Figure 2.4).

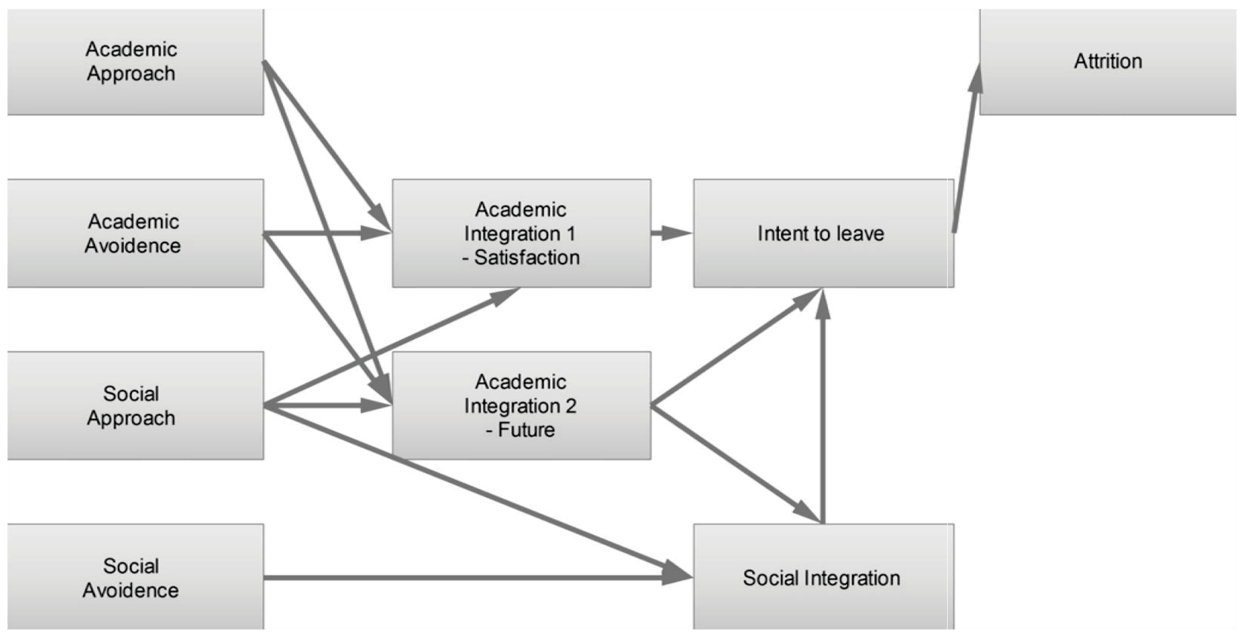

Figure 2.4: Eaton and Bean's (Redrawn from 1995: 621) Approach avoidance model

The model took into account the effect of background characteristics on persistence: *student prior educational attainment* (which covered high school grade-point average and number of university preparatory courses taken), and *family educational attainment and support* (which covered student family educational attainment and how supportive the family had been in the students' studies).

The variable *intent to leave* had the most predictive power of *student attrition* followed by *family educational attainment and support.*

The group of variables which strongly interacts with intent to leave were; *current academic integration*, *future academic integration*, and *social integration*, which indicates that if students perceive themselves as being successfully integrated into the university environment, both socially and academically, then they will tend to persist with their studies.

Integration of student retention models

It was argued by Cabrera, Castañeda, Nora, and Hengstler (1992) that further development of an integrated model of the two dominating *student retention* models would provide better explanatory value in modelling the process of *student retention* and *student persistence*. To evaluate, compare, and contrast both the Student Integration Model and Student Attrition Model, (how much variance each accounted for) Cabrera, Castañeda, Nora, and Hengstler (1992) surveyed 2453 full-time first-year students, who were younger than 24 years old, at a United States university. The survey used was designed to measure variables from both models.

The variables with high explanatory value for *student departure* were: *frequency of contacts with faculty and academic staff*, *interactions with* *faculty and academic staff*, *faculty and academic staff concern for student development*, *academic and intellectual development*, *peer relations*, *values*, *certainty of institutional choice*, and *goal importance*.

Cabrera et al. (1992) found that both models had explanatory value regarding *student retention*, and therefore argued that there is a need to further develop models that encompass both the Student Integration Model and the Student Attrition Model. Due to the wide variations within empirical trials and findings associated with Tinto's model, researchers have argued that it should be "seriously revised" (Braxton, 2000: 258; Braxton and Hirschy, 2004). Braxton (2000) has even suggested that a new foundation for such a model needs to be developed. While some researchers see these models as separate and distinct, I would argue that it is important to acknowledge that both models "*regard persistence [retention] as the result of a complex set of interactions over time*" (Cabrera, Castañeda, Nora, and Hengstler, 1992: 145). Thus, if student retention research is to move forwards, it is important to find new ways to model *student retention* as an integrated whole.

Introduction to complexity thinking

Introduction

Earlier I described how researchers in the field of student retention research have employed a wide set of constructs from different fields of study to try to explore and model the underlying processes for *student retention*. Although, the “complex nature” of *student retention* has been recognized, it has only been used to account for inaccessible aspects and relations in previous models. I argue that what is then lacking in dealing with the “complex nature” of *student retention* is the implementation of the tools that become available when taking on a complexity thinking perspective.

In this section, I present the concepts that are drawn upon to exemplify the use of complexity thinking to produce a more powerful and complex modelling system of *student retention*.

What is complexity thinking?

Complexity thinking is defined as “a way of thinking and acting” (Davis and Sumara, 2006: 25) derived from complexity theory. Complexity thinking can be used by researchers which are interested in non-linear, complex and multilevel systems. Complexity thinking is a mindset used to frame a problem situation that can be identified as a complex system in the term of reference of complexity theory.

What is complexity theory?[8]

Complexity theory aims to describe and understand complex systems and their capacity to show order, pattern, and structural contour of systems. Especially important is how these orders, patterns and structures seemingly emerge spontaneously, in the absence of centralized control, from interactions between the complex systems' components. Complexity theory has taken root and emerged within a wide range of disciplines, generating a theory that essentially "transcends disciplines" (Waldrop, 1992, who gives a detailed outline of the historical development of complexity theory. Also see Mitchell, 2009, who gives an overview of current applications of complexity theory in a wide array of fields). Complexity theory is not characterized by a particular research method but by a methodological perspective (i.e., a way of thinking) that employs a range of methods to study complex phenomena (Davis and Sumara, 2006).

Complexity theory is often pitted against so called "classical science", which is, in turn, portrayed in terms of reductionist efforts to condense phenomena into their "simplest components". In complexity thinking terms, *complex phenomena* are distinct from *complicated phenomena* which are mechanical, predictable and can be fully understood by examining their component parts. To obtain a reasonable portrayal of a complex phenomenon, an understanding of the properties of the components alone is not sufficient. Thus, what is central in describing or understanding a complex system is identifying the components, their interactions, and the higher order behaviours and properties that emerge from the complex system, such as system behaviours, properties and structures or the "structuring structures"

[8] For consistency and coherence in the main body of the thesis, the description in this section is largely a repeat of the overview given in Paper I.

(Bourdieu, 1984) of the complex system (cf. Davis and Sumara, 2006). In this way, a case can be made to characterize complexity theory as distinctly different from a traditional view of the "power of prediction". In other words, the evolution of a complex system is, in a classical sense, largely unpredictable and uncontrollable.

One can conceptualize the essential aspects of the structure, dynamics and predictability of complex systems through metaphors (for example, see Gilstrap, 2005), computer simulations (for example, see Brown and Eisenhardt, 1997) and systems of modelling (for example, see Mowat and Davis, 2010). The essential aspects of complex systems, and what have given rise to complexity theory's ubiquitous emergence, are that all complex systems share similar structures and dynamics. The behaviour of complex systems such as society, organisms, or the internet can only be conceptually discussed as somewhere in-between complete order and complete disorder, and any attempt to measure or distinguish one system as "more complex" than another often breaks down (Mitchell, 2009). If a system is to be identified as being a complex system what needs to be investigated is the presence of structures and dynamics that are common among complex systems, not the complexity itself (Davis and Sumara, 2006).

The structure contour[9] of complex systems

Complex systems have been found to have a network structure[10] where the *connectedness* of nodes is characterized by a power law distribution. This

[9] My use of "contour" is due it being virtually impossible to get a complete description of a "complex system".

means that there are a few components that are much more connected than others, and thus more "important" for the system. Most components in a complex system have a low connectedness to the system as a whole, i.e., have a low number of connections to other parts of the complex system. This means that a complex system's evolving structure is decentralized. This kind of structure can be contrasted to two other types of networks: (1) centralized networks with only one central node with every other node only connected to that central node; and, (2) distributed networks where all nodes have the same connectivity in the network. Information is spread effectively in centralized networks, but they are vulnerable to breakdown due to the dependency on the central node. On the other hand, distributed networks are robust to breakdowns but inefficient in spreading information. In the case of decentralized networks, when an "important" component is removed or breaks down, then the whole system will suffer considerable damage, however the system will remain stable with the removal of any of the many less important or connected nodes.

Complex systems are scale-free and components within a complex system can also be considered to be complex systems themselves that share similar structures and dynamics. Therefore, complex systems are said to be nested within other complex systems. The borders of a complex system are mostly fuzzy and it is not always possible to distinguish different parts of a complex system. Importantly, nested complex systems do share similar structure and dynamics but operate on different scales (time, size and so forth).

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[10] By structure I mean a *contour view* of a system, which continually changes as elements of the system emerge; the system is a learning system.

Dynamics of complex systems

One key aspect of complex systems is that they are adaptive to their own internal and external interactions. Through recursive adaptations, complex systems self-organize; properties, behaviour and structure all emerge without an external system or an internal "leader system" that controls the complex system.

Components of complex systems interact mainly locally – neighbour-interactions – and this can lead to either positive feedback (pushes the system to a non-equilibrium state) or negative feedback (draws the system to equilibrium). Positive feedback can amplify, and negative feedback can dampen properties, behaviours and structures. The connectedness of each component influences the complex systems' potential for feedback. Depending on how "connected" each component is to other components within the system, the positive or negative feedback can be greatly amplified or dampened, this gives rise to the possibility of a systems' emergence. Through the concept of "neighbour-interactions", one can argue that nested systems that are highly connected can be seen as close (adjacent) to each-other (Davis and Sumara, 2006).

Complexity thinking in education research

Complexity theory has become more anchored in educational research and it aims to describe and understand complex systems and their capacity to show order, patterns, and structure in educational activities (Davis and Sumara, 2006).

The use of complexity thinking in education is a fairly new field of study (Davis and Sumara, 2006) and much of the research in the field has focused on describing education, teaching and learning, knowledge, and epistemology of sciences by employing complexity thinking perspective. The movement towards the use of complexity thinking in education has been propagated by the need to have a theory to provide tools to “grasp the complex processes of learning” (Jörg, Davis, and Nickmans, 2007: 1) that can provide new approaches to inquiries for educational research.

Mathematics *learning-for-teaching* has been modelled as several nested systems: subjective understanding, classroom collectivity, curriculum structure, and mathematical objects (Davis and Simmt, 2006). Each level of complex organization exhibits similar structures and dynamics but operates within different time-scales and in different units of analysis. The subjective understanding can have a faster rate of change than the mathematical objects in society. Thus, these systems can be described as scale free, because at each level of analysis, or scale, similar properties exist such as the power law distribution of node connectedness.

Mowat and Davis (2010), using complexity thinking, described mathematics as a nested system. Moll (2009) completed a seminal work in physics education research illustrating how emotion, identities, attitudes, motivations in learning science in group based science competitions can emerge.

From a complexity thinking perspective, education is not viewed as a linear process where learning is achieved linearly. Instead, education is viewed as continuous adaptation (Davis and Sumara, 2006), where the student and all aspects present in the “complex system” of education affect the recursive adaptation of the student and the complex system of education. The direction of the evolution of the complex system or what the students learn, or how and if they continue their studies, is dependent on both the students and the system in a non-linear way.

Introduction to network theory

Introduction

The orienting emphasis in network theory is “structural relations” between components in a network (Knocke and Yang, 2008). From such a framing the essential components of a network are the nodes (vertices) and the links (connections, edges) between nodes. In other words, network theory is a powerful analytic tool to explore, come to understand, and characterize structure connectivity.

Network theory in education research

The use of network theory and social network theory in educational research has increased due to the extended use of online courses, course web sites, and social networking over the last decade. Especially students’ use of online social networks, such as Facebook, has been in particular focus (for example, see Eodice and Gaffin, 2008; Grabmeier, 2009).

In education research, network theory has also been used, for example, to characterize students interactions in small group discussions (for example, see Bruun, 2011), the relation of students’ formal and informal networks to academic achievement (for example, see Cho, Gay, Davidson, and Ingraffea, 2007), and students’ sense of community (for example, see Dawson, 2008).

Work inspired by complexity theory and social network theory has proposed that social network theory can provide critical epistemological implications for curriculum design (Gilstrap, 2011), but a comprehensive framework of tools that handles the educational complexity of networks still needs to be developed. Gilstrap (2011) suggests using Davis and Sumara's (2006) complexity thinking framework, which consists of much of the work done in the research of complex adaptive networks, and the educational connection between complex systems and practice.

Network theory in student retention research

Social networks have been present, but in the background, in the development of theoretical models used to understand *student retention*, especially in the work of Tinto (1975; 1987; 1997) and the work he crafted his initial model around (for example, see Spady, 1970; 1971; Durkheim, 1897). In this work, the importance of social networks is often discussed, but in a reductionist way; finding ways to capture structures and dynamics of social networks within metaphors or structure them into measurable variables.

In Chapter One, I pointed out that it has been recognized that the field of student retention research needs to employ "network analysis and/or social mapping of student interaction... [to]...better illuminate the complexity of student involvement" (Tinto, 1997: 619). Thus, it has been known for some time that structures of social networks affects different aspects of students' experiences of higher education, such as student satisfaction, *academic performance*, institutional commitment, and study intentions. These aspects, in turn, are connected to *student retention* (for example, see Rizzuto, LeDoux, and Hatala, 2009; Sacredote, 2001; Thomas, 2000).

Network concepts

This section introduces central concepts from network theory. I begin with the first construct of network theory; the *nodes*. The nodes represent components of a network. Secondly, the *edges* represent the relationships or connections between nodes. When two nodes are directly connected, these two nodes are *adjacent.* A node's *total degree* is the number of *adjacent nodes*. A way through a sequence of nodes that begins with the starting node, follows adjacent nodes through the network, and ends at the end node is denoted as a *path* between nodes in network theory. When every node in the network is *reachable* (i.e. there exists a path between every node) the network is *connected*. If there are many paths between two nodes, the distance, and the number of edges in the different paths, can be used to find the *shortest path* between nodes (Freeman, 1978). Using these constructs of network theory, visualization and analysis of networks, and therefore a contour of complex systems, is possible.

Network measurements

I have mainly used the network measurements of *closeness centrality* and *betweenness centrality* to find parts of the network that have the possibility to be critical for the system as a whole (a good introduction to these concepts can be found in Bernhardsson, 2009). *Closeness centrality* is an ordinal measure of how "close" every other node is, and it is calculated through finding the shortest path between nodes. Information can be spread more effectively from nodes with high *closeness centrality* to the whole network (Freeman, 1978). *Betweenness centrality* is the frequency of one particular node as a part of the shortest path between every other node. Nodes that are more frequently a part of the shortest path between nodes are often interpreted as having a high degree of “control of communication” (Freeman, 1978: 224) in the network.

3. Exemplifying the use of complexity thinking

"Adapt or perish, now as ever, is nature's inexorable imperative."

— H.G. Wells

Introduction

This section will explore different aspects of the research question stated in Chapter One:

In order to produce a stronger and more effective grounding, how can complexity thinking[1] *be used to develop informative modelling of student retention for the Higher Education Physics and Engineering context?*

I present illustrative examples, based on three studies, of using complexity thinking to highlight critical aspects of building insightful models into

[1] Thinking that is derived from complexity theory.

student retention in the Higher Education Physics and Engineering context. In doing so, three research themes are covered:

- Complexity thinking having the ability to incorporate previous constructs of student retention research.
- Analytical constructs of complexity thinking being applied to varied sets of data to construct student retention models by taking into account different levels of analysis (illustrated in Paper I, Paper II and Paper III).
- Complexity thinking providing the possibility for further insights into the "complex" system of student retention for students in Higher Education Physics and Engineering.

Studies used to provide illustrations of how complexity thinking can be used to develop informative modelling of *student retention* are provided in Papers I – III.

Ethical considerations of data collection and analysis

The ethical guidelines, provided by the Swedish Research Council (SRC) (Vetenskapsrådet, 2002) and the European Commission (EC) (European Commission, 2010) have been followed both in the planning, execution, data collection, and data analysis within the research project. I made sure that enough time and effort were available and spent on discussions of the ethical aspects with the participants.

Both the SRC (Vetenskapsrådet, 2002) and the EC (European Commission, 2010) emphasize the importance of informed consent. In every instance of data collection, the participants were informed verbally and in text of what the data they provided was going to be used for, and by whom (Appendix 1). Furthermore, the SRC and EC put strong emphasis on the voluntary participation in the study. As such all participants have been provided with my contact information as they were informed that their participation was voluntary and that they could withdraw their participation at any time before the results of the analysis was published. Students were informed that if they did not want to take part in the survey they could leave or they could wait for a while and hand in a blank survey questionnaire.

SRC (Vetenskapsrådet, 2002) and EC (European Commission, 2010) states that all data containing personal information of a sensitive nature needs to be prepared in such a way that it cannot cause harm to the participant in any way. As such, information that could be used for the identification of individuals within the data-set was removed from the analysis and is therefore not present in any of the results.

To protect sensitive personal information, electronic data files that could be used to identify individuals within a data set are stored on a separate hard drive. This hard drive is not connected to the internet. All survey questionnaires are kept under lock and key, and stored in such a way that personnel outside the research division cannot access the data.

I have on several occasions had follow-up informal discussions with some of the participants about the analysis or the results of the analysis. Furthermore, I have kept contact information available for participants whom expressed an interest in how and when the published material would be available. I will send them copies when they become available.

Illustrating the ability for complexity thinking to incorporate previous constructs of student retention research

A critical issue for providing a foundation for a new way forward in modelling *student retention* is that the theoretical foundation that is considered is able to not only incorporate previous findings and constructs, but also to provide tools to further the understanding of *student retention*. I set out to illustrate that complexity thinking has the possibility to incorporate these earlier constructs by using the theoretical tools available from complexity thinking to build a complex model of *student retention*.

Data collection[2]

The data used for the example modelling was collected from two sources: student records and a survey questionnaire.

Student records were used to obtain students' demographic information, such as age and gender, and information regarding students' academic achievement, such as Higher Education Credits achieved inside and outside of the programme, and *student retention*.

A survey questionnaire (Paper I - Appendix I) was developed that drew on previous student retention research and was further developed through discussion with colleagues and students. The questionnaire[3] was based on aspects derived from both the Student Integration Model and the Student Attrition Model which provides high explanatory value for *student retention*

[2] This section is based on the data collection of Paper I.

[3] Explained in detail in Paper I.

(Cabrera, Castañeda, Nora, and Hengstler, 1993). Since the data was to be used only for illustrative purposes, the questionnaire was not subjected to reliability and validity analysis.

The questionnaire was handed out to students during the end of their first year (second semester) of university study in 2009 at a typical first-year physics course at a highly regarded traditional Swedish university. To maximize questionnaire-completion, a venue that facilitated a discussion of aims and the associated ethical considerations was chosen. Most students (51) present at the venue agreed to participate in the questionnaire. Thirty-two of the participating students were registered for a four and a half year Master of Science Programme in Engineering Physics, twelve were registered for a three year Bachelor of Science Programme in Physics and the remaining seven were registered in a four and a half year Master of Science Programme in Materials Engineering.

Using the created questionnaire, Paper I explores and exemplifies how complexity thinking could be used in research aimed towards modelling a complex system of *student retention* of students in physics and engineering programmes. It focuses on how attitudes, beliefs, self-reported experiences, Higher Education Credits Achieved, physiological gender, age, and retention are interlinked and how it could be modelled to organize as a self-organized networked nested complex system by the use of multidimensional scaling and network theory.

Complex systems are networked constellations of components, which in this example are the students' viewpoints of their experience of higher education in the first year. Each item is considered to emerge from and be nested within multiple complex systems. Given the decentralized networked nature of complex systems, analysis of the structure and dynamics of a complex system of *student retention* is possible through, but not constrained to, exploratory factor analysis, multidimensional scaling and network theory.

Analysis

Using the questionnaire results, multidimensional scaling was used to calculate the distances between points of data in multidimensional space. The relative closeness between items is seen as the “likeness” or “similarities” (Schiffman, Reynolds, and Young, 1981) of those items. By creating this multidimensional space it is possible to calculate transformed “multidimensional proximity” (relative closeness) between items.

According to complexity thinking, components of a complex system interact locally (Davis and Sumara, 2006), and therefore one could argue that components (items on the questionnaire) that have a high relative closeness to other components in the multidimensional scaling analysis can be regarded as being connected[4] and within each other’s “zone of influence”. In the multidimensional scaling analysis of the survey data, the answers and their similarities were regarded as a representation of the complex system’s emergent structure. This affords the possibility to create a basis for visualization and measurements of component interaction through the use of network theory.

[4] “Connected” is used as a broad term that encompasses the interaction, communication, and dependence between the different components of the system.

Network measurements and interpretation

The network is created as an undirected network. In an undirected network the edges have no direction but will be used to represent the connections between the nodes. Analysis of the created network was done by using Statnet (Handcock et al., 2003), which is a freely available package for "R" that is designed for analysing networks. Identification of "important" nodes can be done by analysing each node's *centrality*.

Results

Using the respondents' questionnaire answers it is possible from the above described analysis method to provide an illustration of the complex networked system (Figure 3.1). I call this visualization an illustration, as the networked model presented here has had many of its less important components removed in order to bring out the more important components and connections. However, I still propose that this illustrative model has the possibility to contain complex interrelationships (due to its networked nature) and structures for differentiation in information feed-back and feed-forwards (as shown by the *closeness centrality* and *betweenness centrality* analysis, Figure 3.2). It thereby contains "structural affordances" for all components to impact on *student retention*. Even though every part of the network has the possibility to have an impact on retention, the main impact of all items in the analysis is theorized to be through other constructs.

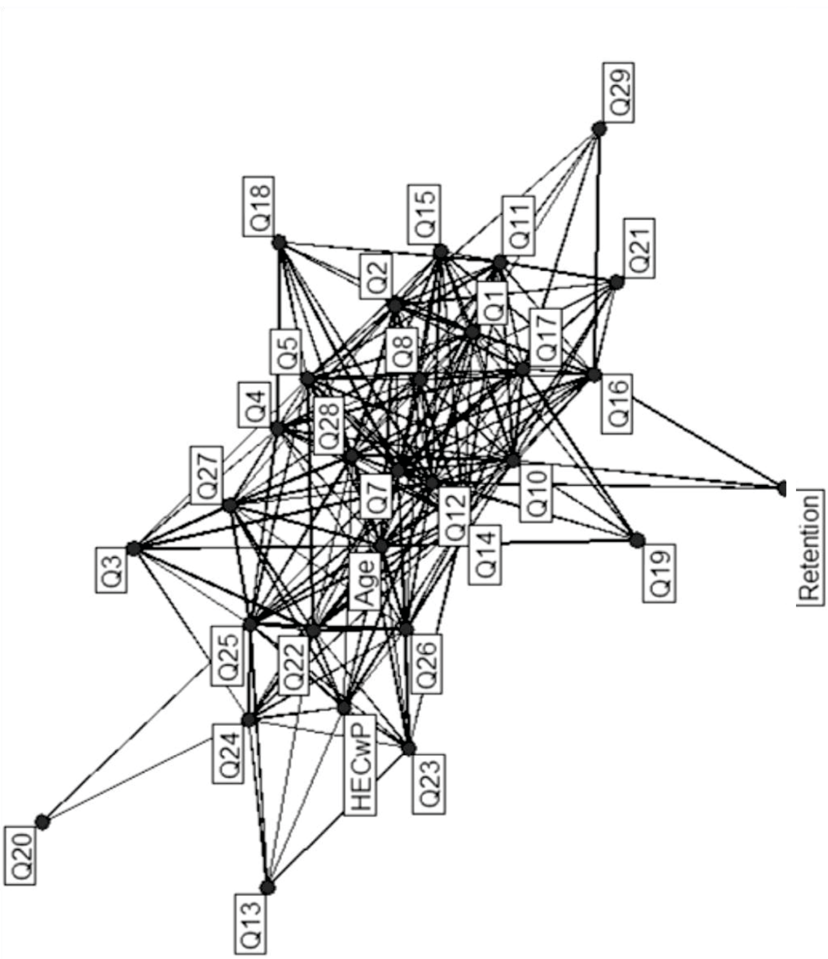

Figure 3.1: Illustrative example of a contour of a complex system of student retention.

Furthermore, it is possible to identify the critical components of this network model through network measurements of *closeness centrality* and *betweenness centrality* (Figure 3.2). Nodes with high *closeness centrality* and high *betweenness centrality* both distribute information effectively to a large proportion of the system, and are in a position of "control" of other nodes' influences on the system. Figure 3.2 shows nodes that are "close" to other nodes and nodes which have a high frequency of being "between" other nodes and consideration of Figure 3.2 shows that there are seven items with relative high *betweenness centrality* and *closeness centrality.* These are:

- [Q12] institutional quality,
- [Q7] satisfaction with one's course curriculum,
- [Q25] faculty support,
- Age of the students
- [Q14] students' satisfaction of being at the university,
- [Q10] the feeling of belonging at the university, and
- [Q28] students view physics as connected to everyday life.

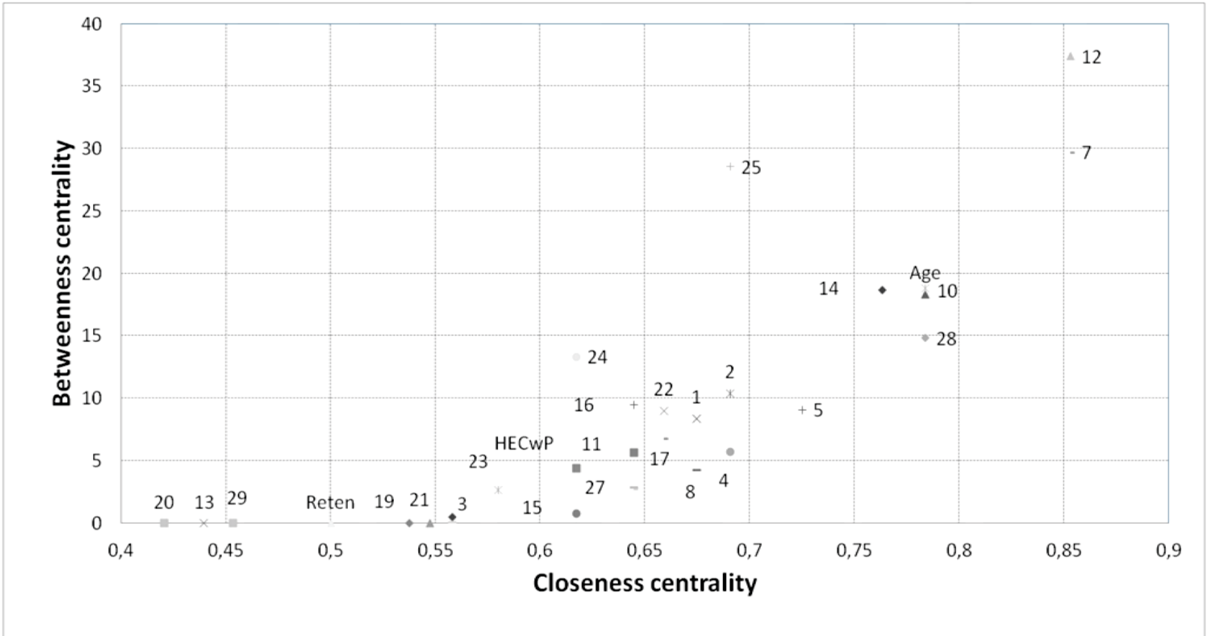

Figure 3.2: Closeness centrality and betweenness centrality scatter plot of the network created by the multidimensional scaling analysis proximities of items. All numbered markers corresponds to same number question. Marker "reten" corresponds to the measurement of student retention. Marker named "HECwP" corresponds to students' Higher Education Credits achieved Within Programme. Marker "Age" corresponds to the age of the students.

One item, [Q25], *faculty staff has provided me with the support I needed to succeed in my studies*, stands out because even though the *closeness centrality* is relatively low, it has high *betweenness centrality*. It is possible to interpret this as meaning that the component may present a possible *gateway for influence*[5] within the overall complex system of *student retention*.

It is important to note that this analysis uses constructs from both from the Student Integration Model and the Student Attrition Model in a new way. It suggests that these components of *student retention* are not independently incommensurable components, but every earlier construct is a part of a whole. The analysis opens a possibility for new ways of evaluating the different constructs of modelling for their importance for the system as a whole.

If complexity thinking was not applied in the analysis of the data, it could be easy to end up only paying attention to the factors which are *close* (i.e., directly linked) to the variable *retention*; [Q10], *I feel I belong at this university*, [Q12], *My close friends rate this university as a high quality institution,* [Q16], *I am confident I made the right decision in choosing to attend at this university*. This could cause [Q16] to be identified as a very important aspect of *student retention*, while in the networked analysis it is only in the middle of the *closeness centrality* items, and has very low ”control” of the information flow in the system (*betweenness centrality*) and other critical aspects of *student retention* would be ”hidden” in the analysis e.g., [Q7], *I am satisfied with my course curriculum*, [Q14], *Students'*

[5] A *gateway of influence* could be seen as a component in a networked structure that could potentially cause a cascading effect of influence in the whole system. On the other hand, it could also greatly dampen (or even completely block out) any other influence in the system.

satisfaction of being at the university, [Q25], *faculty support,* [Q28], *first year physics courses have been inspiring,* and *the age of the students*. This indicates that using complexity thinking and the available theoretical tools can show new ways to move forward with research into *student retention*.

Illustrating the use of complexity thinking in different levels of analysis within a contour of a complex system of student retention

As retention has significance on many societal levels (for example, see Forsman and Andersson, 2010), and is important at course, programme and university levels, it is critical that the theoretical framework of complexity thinking is applicable and provides tools to find answers to research questions at different levels of a university. This section will present results at three different levels of analysis from three studies (Paper I, II, and III).

Firstly, analysis of the different items on the questionnaire in Paper I was modelled as a nested system. This paper was to illustrate how different parts of a complex system of *student retention* could be considered levelled or nested within each other.

Secondly, the focus is directed to the social (and academic) networks of students in Paper II to explore the emergent behaviour of those networks.

Thirdly, students' supportive systems come into focus to explore structures of the supportive systems, but also to theorize about their evolution.

Nested systems

To create an illustrative model of different nested systems within students' experience of the university, I used data from Paper I and analysed its multidimensional structure through exploratory factor analysis to explore the possible nested structure of a complex system. This was to create a model for different levels of the complex structure.

Analysis

Exploratory factor analysis is used to study patterns and order within multidimensional data in a multidimensional space. In this case, a useful way to view the exploratory factor analysis is to see it as essentially what Hofstede, Neuijen, Ohayv, and Sanders, (1990: 299) call "ecological factor analysis" – an analysis where the stability of the analysis does "…not depend on the number of aggregate cases but on the number of independent individuals who contributed to each case".

The variables used in the analysis are provided by the students answers from the questionnaire responses. Exploratory factor analysis considers these items to have "commonalities" (Kim and Mueller, 1978) which are constituted using the covariance between the items, and thus groups them accordingly into factors. This implies that components (items on the questionnaire) that have commonalities have higher covariance and greater significance than components that are far apart. From a complexity thinking perspective, these "commonalities" are interpreted as a self-organized pattern of different nested systems. I argue that the factors provided by the exploratory factor analysis can be considered as separate nested systems of a complex system of *student retention* in higher education.

Exploratory factor analysis has the potential to show that some of the components will be present, and have a high enough projection (loading value), in one or more factors. In this study it is interpreted that components are playing a role within multiple nested systems and the systems' shared interaction.

Results

Four factors emerged from the exploratory factor analysis. For illustrative purposes[6], they have been characterized as: Degree Programme Components (*Factor 1*)*,* Social Components (*Factor 2*), Institutional (quality / reputation) Components (*Factor 3*), and Supportive Components (*Factor 4*).

Interpretation of factors from the exploratory factor analysis was guided by using network theory and complexity thinking. Thus, each factor is characterized as a *networked* component; "a group of nodes that are mutually interconnected." (Proulx, Promislow, and Phillips, 2005: 345). Furthermore, complex systems are networked constellations of components, which means that the result can be interpreted as each factor (i.e., *networked* component) providing a contour of a complex nested system. The choice was to visualize and analyse the adjacency of the complex nested systems (Figure 3.3, left side) and then rank them by their relative size (Figure 3.3, right side).

According to complexity thinking, nested systems have fuzzy borders and can share components. Thus, adjacency was analysed using the number of items they share (see Table 3.1): *Factor 1* shares two items with *Factor 2*,

[6] The current data analysed does not contain a sufficient sample size for a stringent exploratory factor analysis, thus the characterization of the different identified systems is an illustrative example.

Factor 2 shares five items with *Factor 3* and one item with *Factor 4*, and *Factor 3* shares one item with *Factor 4*.

Items	Factor 1	Factor 2	Factor 3	Factor 4
H.E. credits programme (HECwP)			0.542	
Retention			0.934	
Q1. Best university programme	0.788			
Q2. Family approval		0.472		
Q3. Satisfied with finances				0.836
Q4. Finances - focus on studies				0.833
Q5. Finances - teacher demands				0.796
Q7. Satisfied with curriculum	0.328	0.458		
Q8. Close friends encouragement		0.580		
Q10. I belong at my university		0.637	0.447	
Q11. Future employment	0.464	0.390		
Q12. My close friends rate this institution as high quality			0.313	
Q14. Satisfied with experience of higher education		0.687	0.411	
Q15. Easy to make new friends		0.842		
Q16. Right choice - university		0.683	0.399	
Q17. Right choice - programme	0.758			
Q19. It is important to get a degree from this programme	0.708			
Q21. Initiation weeks		0.855		
Q22. First year courses fit together				0.459
Q23. Previous knowledge		0.385		
Q24. Clear educational trajectory		0.447	0.396	
Q25. Faculty support		0.345	0.322	0.461
Q29. I intend to re-enroll	0.835			

Table 3.1: Loading from the exploratory factor analysis giving the factors sorted adjacently by the number of shared items. Light grey shading denotes the items that have a loading above 0.32 in more than one factor

The creation of a “networked” schema of the links between the different systems (Figure 3.3, right side) was created. The number of components with a signifcant loading in the factor is used for a schematic “size characterization” to model the systems as a nested complex system in Figure 3.3 (left side).

As mentioned in a previous footnote, it is important to note is that the current data analysed does not contain a large enough sample size to do a stringent exploratory factor analysis, thusly the following characterization of the different identified systems are an illustrative example, on how one could, provided sufficient sample size, characterize these systems. More details of the statistical analysis are present in Paper I.

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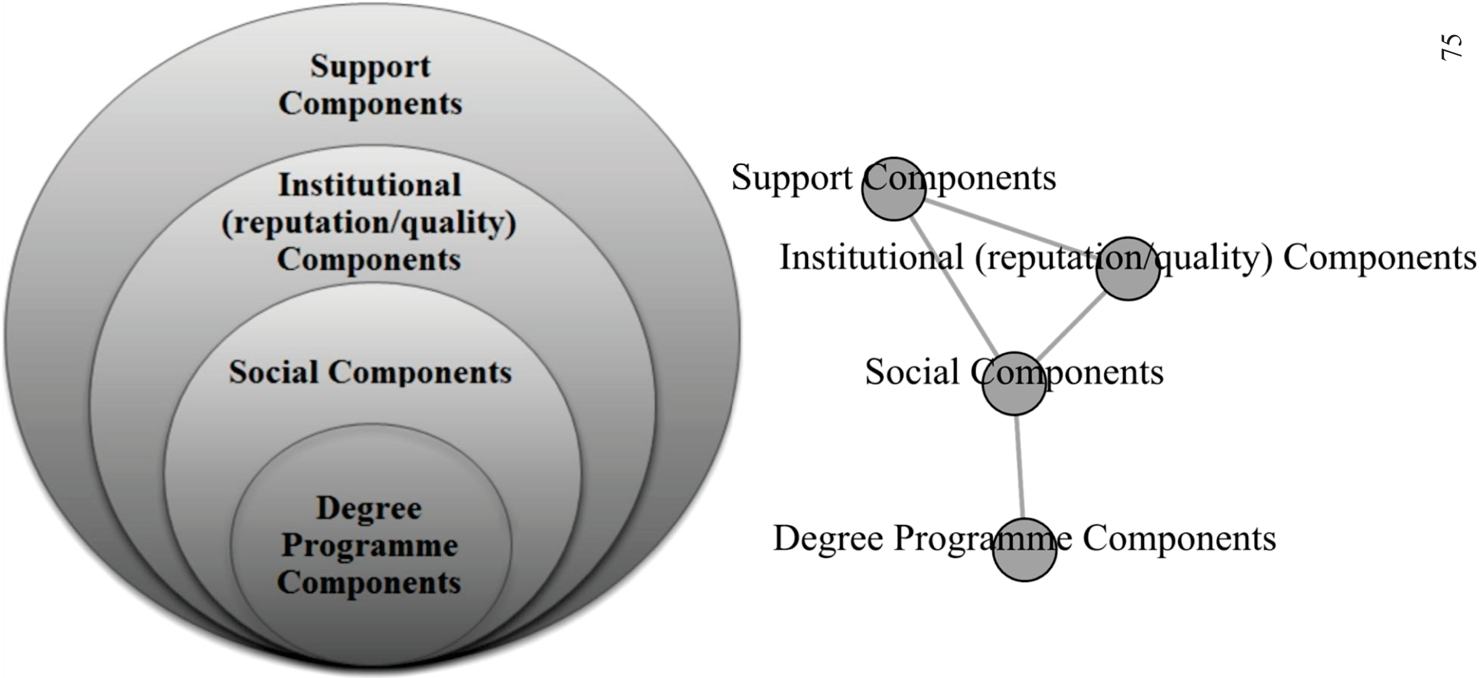

Figure 3.3: Two schemata of complex systems of student retention in higher education.
Right side: A way of visualizing the complex systems' networked adjacency.
Left side: A way of visualizing the nestedness of the complex systems

Supportive Components

Supportive Components are mainly composed of *financial attitudes and satisfaction*, *university reputation*, and *family support*. The financial aspect is central to the *Supportive Components* in this model. Three items in the questionnaire asked students about their financial situation and the most important influence on the complex nested system of *student retention* was found to be students' feeling that their financial situation gives them the freedom to focus on their studies. As mentioned earlier, financial impact has empirically been found to be significant in other earlier attempts to model *student retention* (for example, see Cabrera, Nora, and Castañeda, 1993; Paulsen and John, 1997).

Although the item corresponding to the students' families has a loading (0,314) below the cut-off (0,32) and thus did not meet the loading criterion for exploratory factor analysis, I still consider it to be an influence in *Supportive Components*. Other earlier research such as Bean (1982), Spady (1970, 1971) and Bean and Metzner (1985) have proposed that family approval is a part of the reason why students continue with their university studies.

Through its orientation in the nestedness of a complex system of *student retention*, *Support Components* has the largest time scale for change. Furthermore, a weak link is present between *Support Components* and *Social Components*, as they share the item "*Faculty Support*" (see Table 3.1 and Figure 3.3, right side).

Social Components

Social components are made up of parts of the everyday life of individuals situated at a university, for example, students, teachers and the social spheres that they inhabit. Making new friends (Spady, 1970; 1971; Tinto, 1975; 1987, 1997; Bean and Metzner, 1985), the initiation weeks at the university, and friends' encouragement to continue with one's studies (Bean, 1980; Stratton, O'Toole and Wetzel, 2008) are central to *Social Components*. Furthermore, Kuh and Hu's (2001) general sense of "satisfaction" students experience while being at a university is also present in *Social Components*.

Other members of the students' social sphere emerged as components of this system through the items in the component "Faculty support". Furthermore, the item "belonging" is also a part of this system which could indicate that social connections with both fellow students and teachers are important to fostering a "feeling of belonging" at the university (Tinto, 1975; 1987; 1997).

Other aspects such as the classroom experience of learning have also been found to be important (Lasry, Mazur, and Watkins, 2008). Having university courses that "felt like" a continuation of one's pre-university schooling plays an important positive role in student retention. This outcome resonates well with Tinto's (1975; 1987; 1997) conclusion that "prior schooling" experience is strongly connected to *student retention*.

Social Components has its strongest connection to *Institutional (reputation / quality) components*. *Social Components* are also weakly connected to *Supportive Components* by sharing one item in the results of the exploratory factor analysis: students' feeling that they are satisfied with their course curriculum, and students' feeling that their degree will be important for them for future employment.

Institutional (reputation / quality) Components

Successfully completing the courses that are a part of a programme is typically part of the formal requirements to continue to the next year of study in a programme. The students' course completion and thus achieving the Higher Education Credits for that course, is a part of *Institutional (reputation / quality) Components*. By completing the courses, students decrease the risk for what Tinto (1975) calls "academic dismissal" (except that in Sweden no direct academic dismissal is allowed). However, programmes have courses that have pre-requisites, which if not successfully completed, become obstacles to programme progression. Also, a lack of stipulated academic progress does lead to a loss of financial support from the Swedish government. This may be why our modelling shows that if students successfully complete their programme courses, the tendency is for them to continue to progress in their programme studies.

A well-known component in student retention research is the "feeling of belonging" at the university (for example, see Tinto 1975, 1987, 1997; Bean, 2005). In my analysis, it is part of *Institutional (reputation / quality) Components*. The students' feeling of belonging is also strongly connected to *Social Components*. Aspects of belonging at the university, such as being satisfied with the experience of higher education, and students' feeling that they made the correct choice in choosing a particular university, are also a part of *Institutional (reputation / quality) Components*.

In the analysis, it is also found that the students' friends' sense of the university's reputation as a high quality institution emerged as important, confirming results from Sung and Yang (2008). This has also previously been found to be important when choosing one particular university over another (Jian et al., 2010).

In the modelling in Paper I, “Faculty support” is also a part of *Institutional (reputation / quality) Components*. Such faculty support and faculty interactions are aspects that have been connected to *student retention* for a long time (for example, see Spady, 1970, 1971; Astin, 1977; Hovdhaugen and Aamodt, 2009; Stump et al., 2009).

The most dominant part of *Institutional (reputation / quality) Components* is the measurement of *student retention* (all the components in of *Institutional (reputation / quality) Components* are closely connected to *student retention*).

Institutional (reputation / quality) Components has its strongest connections to *Social Components* through sharing the following five items from the results of the exploratory factor analysis: *Students' feeling of belonging at the university*, *students being satisfied with the experience of higher education*, *students' feeling that they have made the right choice of university study*, *students' having a clear educational trajectory*, and *students' feeling that the faculty is supportive*.

Degree Programme Components

This system contains items that correspond to the students' attitudes about their degree programme and their experiences of higher education. *Degree Programme Components* is made up of six items relating to programme choice, and degree importance: students' views about their own programme, their choice to study in the particular programme (Reay, 2008), their satisfaction with their course curriculum (Cabrera et al., 1993), the importance of a degree (Tinto, 1975; 1987; 1997; Bean, 1980) from a particular programme, that the degree will secure future employment (Bean, 1980; 2005), and students' own plans of re-enrolling in the programme (Bean, 1980; Braxton, 2000; Braxton et al., 2008; Pascarella et al., 2008).

As illustrated in Figure 3.3 (right side), *Degree Programme Components,* is nested within *Social Components*, *Institutional (reputation / quality) Components*, and *Support Components*, which implies[7] that *Degree Programme Components* has the shortest time scale for change.

Social and academic systems

I have discussed different levels of analysis. I now continue this discussion by bringing the level of analysis closer to the student (which is presented in Paper II). My discussion begins by focusing on the emergence of students' social and academic networks. In other words, I am delving into the integral parts of students' social networks and academic networks and the possible presence of theorized[8] *social system* and *academic system* of the university.

Data collection

An exploration of the emergence of structure of dynamics of social and academic networks began with a *network questionnaire* that was given to three physics and engineering classes at a Swedish university at the end of the Spring term 2010. Following Morrison (2002) the students were asked to write down the names of the people in the class that they interacted with and

[7] In complexity thinking, it is argued that "smaller" complex systems have a faster rate of change (Davis and Sumara, 2006).

[8] See the section on the Student Integration Model in Chapter Two.

at the same time to specify the nature of their interactions on a scale from *only social* (1) to *only academic* (5) with *both social and academic* being (3).

To draw connections between their social and academic interactions and programme retention students were asked a series of eight Likert answer questions regarding their attitudes towards their programme and subject of study. The items are a subset of the variables which account for most of the variance in *student retention* according to Cabrera, Castañeda, Nora, and Hengstler (1992).

Two of the classes where the questionnaire was handed out were in the first year of the physics and engineering programme; a Mechanics II class (Group One) and a Computing Science class (Group Two). One year three class in an engineering programme was also surveyed; Solid Mechanics[9] class (Group Three). The total population of Group one consisted of 154 students. Sixty eight of these answered the questionnaire and 54 more were mentioned in the responses. In Group two, the total population consisted of 113 students. Sixty six of these answered the questionnaire and 41 more were mentioned in the responses. Four more students, outside the surveyed population, were also mentioned. The total surveyed population of group three was 43 students. Twenty three of these students answered the questionnaire and three more where present in the responses. No students outside of the surveyed population were named in the responses.

Analysis of the student networks were conducted using network theory (as previously described in the chapter on Network Theory).

[9] A course dealing with stress and strain in solid materials

Results

Using Gephi 0,7 beta, network representations were created and interpretation of these visual representations of the combined, social, and academic networks, show that they share similar structures within each group (Figures 3.4, 3.5, and 3.6). For each group, the academic network is more likely to display a group of students that are disconnected (or more disentangled) from the larger network. Most of the students seem connected in the combined network for each group. Visually, each group is dissimilar in their topology from each other.

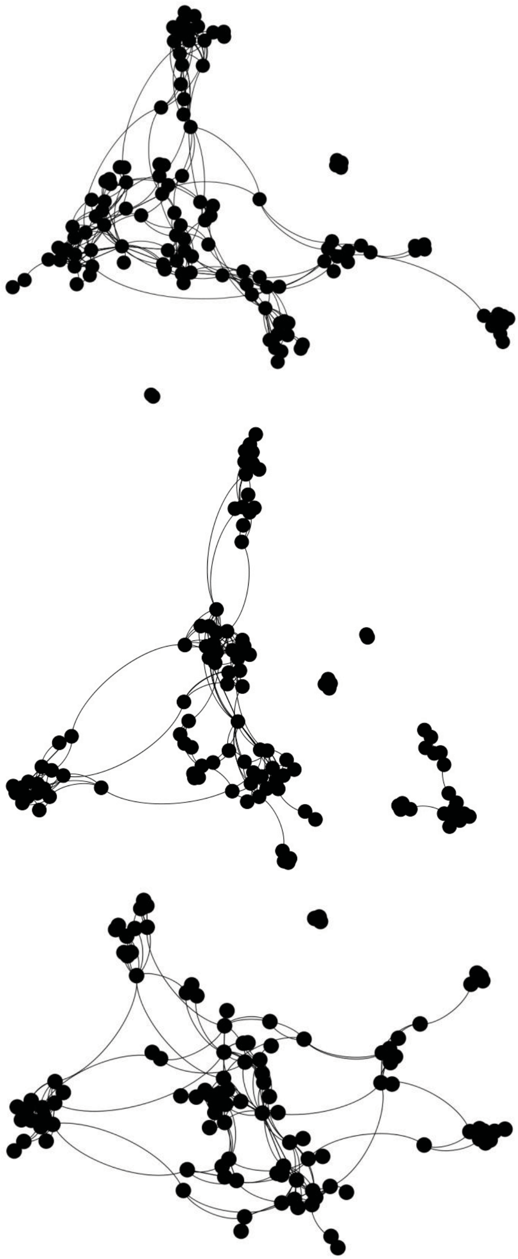

Figure 3.4: Network visualizations for Group One (all students). (From top to bottom) The combined, social, and academic networks.

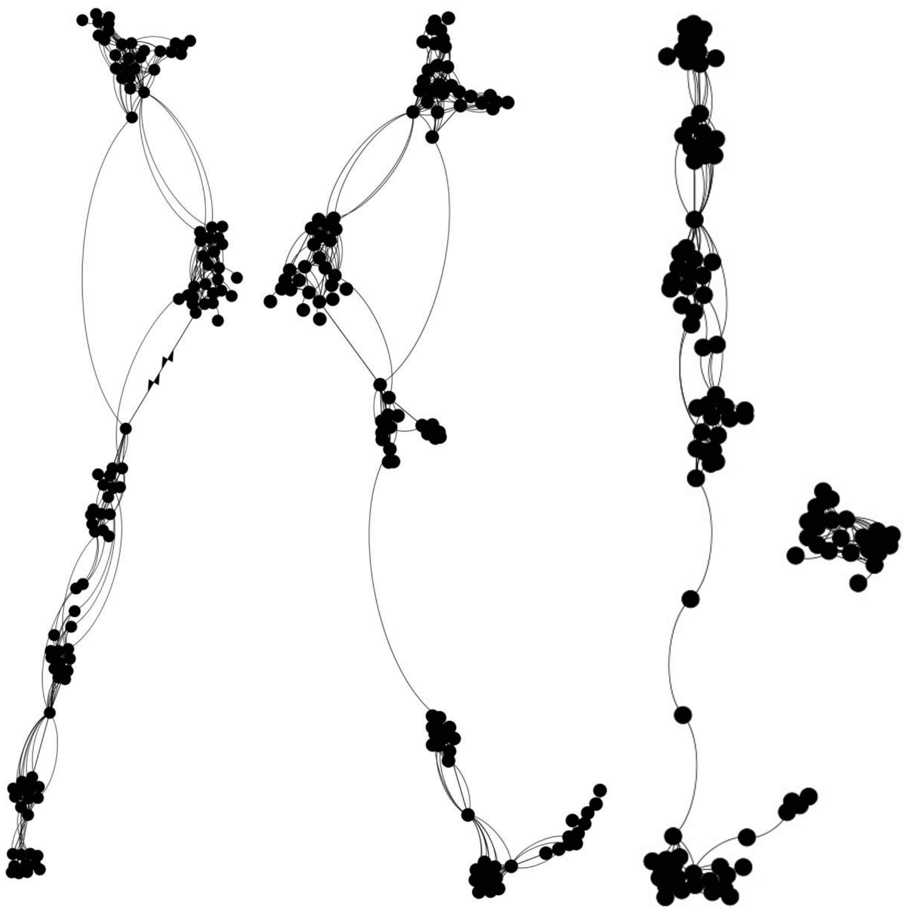

Figure 3.5: Network visualizations for Group Two (all students). (From left to right) The combined, social, and academic networks.

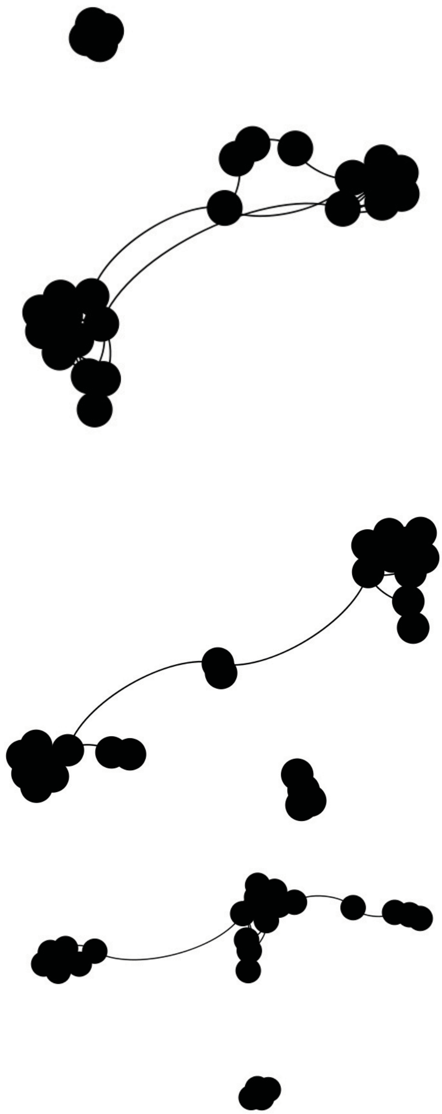

Figure 3.6: Network visualizations for Group Three (all students). (from top to bottom) The combined, social, and academic networks.

Degree Distribution[10]

An analysis of the networks' *degree distributions* (number of nodes characterized by their *in-degree*) was carried out to explore which networks share similarities within the same group, across groups, and across years. A calculation of the *degree distribution* was carried out for all types of networks and for each of the two versions (all students and surveyed students). To analyze the *degree distribution* of the networks, a logarithmic $p(k_{in})$ vs. k_{in} plot was constructed where $p(k_{in})$ is the probability to find such an *in-degree* (k_{in}) in the network. A best fit regression analysis was conducted to evaluate which networks most closely resemble a complex system (since complex systems have a *degree distribution* that can be described by a power law function).

The combined, social, and academic networks of all students in Group One strongly resemble complex systems, that is, they have a power law *degree distribution* with a mean R^2 of 0,83 and the mean R^2 for the version containing only surveyed students was smaller, 0,73. The student networks of Group Two, share some structures of complex systems. For all three networks, with all students present, the mean R^2 of the power law distribution fit was 0,57. In the versions of the combined, social, and academic networks with only the students taking the survey present, only the academic network's *degree distribution* could be described as a power law distribution (R^2 = 0,48). Group Three, showed only a slight resemblance to a *degree distribution* with a weak $p(k_{in})$ maximum around average degree of the nodes in the network, that suggests that it has a structure that is similar to a random decentralized system. No significant regression of *degree distribution* could be carried out to show self-similarity (mean R^2 = 0,04).

[10] This section is based mainly on analysis from Paper II.

The difference in power law *degree distribution* between Groups One and Two, show that the students in the combined, social and academic network of Group One had more low degree nodes than in Group Two, but that they both exhibit a *degree distribution* that can be characterized by a power law. Groups One and Two are both first-year classes and there is evidence that the social, academic, and combined networks that students form within their engineering and science classes during the first year of their programme are more similar in structure to each other than to the year three group and that they share more similarities with complex systems (i.e., the *degree distribution* has a power law distribution and points to decentralized structure).

Degree distribution analysis results indicate that both versions of the student networks (one with only surveyed population and one which includes all students who were named in the surveys) produced similar results. Thus, it is possible to conclude that it is valid to analyze the data using networks with all of the students present even though some were not a part of our surveyed population.

Student Cliques[11, 12]

Using *modularity* (Newman & Girvan, 2004) "*cliques*" (groups of students within a class or group) were identified in the combined, social, and academic networks. A stable *clique* was defined as when at least 80% of the clique members were connected to each other in the combined, social, and

[11] "Clique" is a term used in describing groups or small communities within social network theory.

[12] This section is based on the results from Paper II.

academic networks. My analysis suggests that most *cliques* are inclined towards stability for all the studied populations. Analysis found 17 different *cliques* in the different networks. Results show that 76% of all *cliques* are stable across all three networks in the surveyed populations. Eighteen percent are split in the social network but stable in the combined and academic network, and 6% are split in the academic network but are stable in the combined and social network.

Analysis of clique membership and students' choice of programme was conducted using cross-tabulation in SPSS. An example visualization of Group One's clique members and their programmes of study is presented in Figure 3.7, and it shows that programme is an important predictor of a students' membership in a *clique*. Similar trends were observed for Groups Two and Three.

From Figure 3.7 it is possible to argue for seeing the presence of *communities of practice* (Lave and Wenger, 1991). Wenger (1998) argues that shared practice is the *glue* that holds communities together. The programme attachment of each grouping of student *cliques* could be considered an indicator that communities of practice are formed within the student group.

Figure 3.7 *The combined network of Group One with cliques and programmes represented. The smaller nodes represent individual students and the larger nodes represent the students' programme.*
Note: The shading on smaller nodes identifies the clique membership. The shading on larger nodes indicate that each node corresponds to a different degree programme.

Structural dynamics of social and academic networks[13]

The next step was then to identify how students' structural positions in the social or the academic network are connected to *student achievement* and other indicators for *student retention*. Network measurements of students' structural centrality (*closeness centrality* and *eigenvector centrality*) and node degree (*in-*, *out-* and *total degree*), from all three networks of each group containing all students who were present in the network survey were correlated with course grade and degree of course completion using Pearson's correlation. Students' course grades were within the range of fail (0), Pass (3), and towards higher grades of (4) or (5).

Group One had 48 students who passed or had a higher grade, and 75 students did not complete the course, Group Two had 105 students who passed or had a higher grade, and six students who did not complete the course, and Group Three had 20 students passing or getting a higher grade, and three students who did not complete the course. The courses provide partial credits for completing separate pieces of the course. The degree of course completion ranged from zero to five, with incremental steps for each part of the course completed.

Correlation analyses were also carried out between network measurements of the combined, social, and academic networks and responses to a questionnaire based on student retention research. Only two items out of a total of eight in the questionnaire were analyzed and found to be significant in this context: Q6 – *It has been easy for me to meet and make friends with other students at this university* and Q8 - *I will re-enrol at this programme next semester.*

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[13] This section is based on the results from Paper II.

Important to note is that a large proportion of the students in Group Three indicated on their responses that they were planning to study abroad the next semester and therefore would not re-enrol on their current programme.

Closeness Centrality

In analyzing the results of the network measurements of *closeness centrality* it was found that students who are "close" (have higher *closeness centrality*) to other students in the combined and academic network of Group One tended to have higher grades for each of the three networks. However, the combined and academic networks of Group One also had significant correlations between *closeness centrality* and degree of course completion. For Group Two, the second group of first-year students, closeness to other students in the combined network was also tied to degree of course completion. Thus, for Groups One and Two (first-year students) there appears to be a trend between how *close* students are to each other and academic measures such as the likelihood of achieving good grades and course completion rates. These tendencies are stronger in combined and academic networks than social networks.

Students in Group Two, who were close to other students in their social, and combined network had a tendency towards experiencing that they had an easy time meeting new friends. While students in Group One's academic network with high *closeness centrality* experienced difficulty meeting new friends and had a significant negative correlation. Thus, there was a connection but no clear trend between *closeness centrality* and ease of making new friends.

Students in Group Three who were close to other students in their combined and academic network tended to answer that they were not going to re-enrol the next semester. Students in Group Two who were close to every other student in the academic network also had a negative trend in their answer on re-enrolment for next semester. Thus there is a negative trend between measures of *closeness centrality* and intent to persist in the programme (re-enrolment) in both first and third year students, within the surveyed population.

Eigenvector Centrality

The individual characteristics of students who were interacting with students who, in turn, were interacting with many other students (indicated by their *eigenvector centrality*) were explored. I found[14] that Group One had a strong correlation between their *eigenvector centrality* and the course grade and degree of course completion for all three networks. I found a connection between the students with a higher *eigenvector centrality* and students in both the combined and social networks of Group Two and Group Three that tend to experience that they have had an easy time meeting new friends. A negative trend exists between Group Three students' answers on intent to persist in their studies (re-enrol in the next semester) and the *eigenvector centrality* of each of the three networks. There are differences among groups on measures of *eigenvector centrality*.

In-degree

Analyzing students' *in-degree* (number of students who indicated in the survey that they studied or socialized with one particular student) of each network, we find no significant correlation to *academic performance* in any

[14] Working with the co-authors of Paper II.

of the groups' social networks. In Group One and in Group Two, the first-year students, we find that the *in-degree* of the students' academic network has a significant correlation to course grade.

Group One is the only group where we find that the *in-degree* of students has a significant correlation to the degree of course completion and this is present in the combined and academic network.

For the students' combined and social networks in Group Two and Group Three, we find significant correlations between *in-degree* and their answer of their experiences in meeting new friends. Furthermore, we found a negative trend for Group Three in their intent to persist in their studies (re-enrolment in the next semester) and the *in-degree* of the combined and social network.

Structural connections

Does it then mean that if one student has a particular important position or is a part of an important structure in one type of network (for example a social network), it holds the same importance in the other types of networks? The study in Paper II sought to look for differences between social and academic networks, thus network measures (*in-degree*, *closeness centrality*, and *eigenvector centrality*) for the social and academic networks for each group were compared to each other. Comparing network measurements between the social and academic network, we found positive correlations in all groups of their *in-degree* (number of students that students identified as friends) and *eigenvector centrality* (the connectedness of the students they are connected to). We found that students being close (high *closeness centrality*) to every other student in the social network, does not automatically lead towards a tendency of being close to every other student in the academic network.

Evolution of supportive systems

On a different level of analysis, looking at students' supportive networks and their evolution, an exploratory pilot study (Paper III) was conducted to explore the structure and dynamics of the supportive functions in students' networks. This was to investigate the possibility of modelling the evolution support network function. Students from year one to year five in the Master of Science in Engineering Physics programme at a Swedish university participated in the survey. Thirteen students were asked to draw a network map of the people, places or things they perceived to be supportive of them as a student.

Each of the students were designated a number from a list, this to be able to uphold ethics requirements of the research. Also, this made it possible for the students' to "name" students on their drawn network, if they found someone within the surveyed population to be particularly supportive for them as a student.

Numerical analyses of the students' networks were made through the use of network theory.

Results

From the students' networks, an aggregated supportive network map was created (Figure 3.8) that shows the maximum possible number of supportive functions and how they are interrelated. From the *betweenness centrality* of every node, identification of the supportive functions that have the most *control of the information* (Freeman, 1978 : 224) was possible.

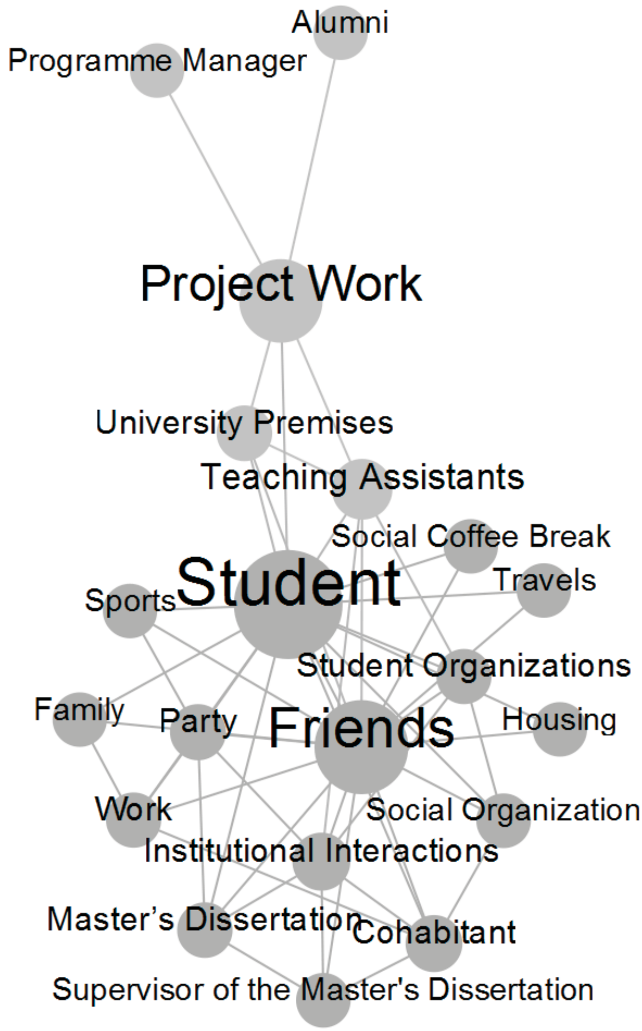

*Figure 3.8**:** An aggregated network map of students’ supportive components and their relation in an ego-network.*

Note: The node “Student” represents each student who drew their supportive network.

From analysis and compilation of the student networks, it was found that the support functions are different between the different students. From how common the support functions are in the various networks that the students answered, classification of support services into two groups was possible: (1) *The frequent*, appearing in eight (out of thirteen) or more student networks, are *Friends*, *Family and Partner*, *Social Organizations*, *Courses and Master's Dissertation*, *Social Activities* and *Student Organizations*. (2) *The infrequent*, appearing in five (out of thirteen) or fewer student networks, were *Work*, *Housing*, *Institutional Interactions*, *Project Work*, *Alumni*, *University Premises*, *Programme Manager*, *Teacher Assistant*, and *Supervisor of the Master's Dissertation*. The *infrequent* support functions were mainly found among those students who were near the end of their degree programme.

From network measurement of *betweenness centrality*, the networked support functions' significance for the evolution of the network can be interpreted. The analysis showed that *Friends*, *Project Work*, *Teaching Assistants*, the *Institutional Interactions*, *Family and Partner*, *Courses and Master's Dissertation*, and *Student Organizations* were the features that were most able to open up for interaction with new support functions for students in this study.

From *the frequent* support function group, identification based on *betweenness centrality* was conducted and *Friends*, *Family and Partner*, and *Student Organizations* were interpreted to have the greatest opportunity to open up pathways to know about and have a link with more support functions. From *the infrequent* group of support functions, identification of *Work*, *Project Work*, *Institutional Interaction*, and *Teaching Assistants* was interpreted as giving opportunities to find new paths to more support functions for students.

Implications

The results of this study suggest that students' connection to supportive functions within a networked framework, serves dual functions; both providing support and allowing the student to come in contact with new supportive functions.

The network analysis implies that new students' supportive networks evolve mainly through *Friends, Family and Partner,* and *Student Organizations,* to later evolve mainly through *Project work, Teaching Assistants,* and *Institutional Interactions*.

However, at this stage I need to remind the reader that this was an illustrative study and further work needs to be done here to ratify this result (see Chapter Five).

4. Implications for using complexity thinking to guide student retention research in a physics and related engineering context

"What really matters is what you do with what you have."
— H.G. Wells

Introduction

The research question, guiding my work is:

In order to produce a stronger and more effective grounding, how can complexity thinking[1] *be used to develop informative modelling of student retention for the Higher Education Physics and Engineering context?*

From the results of the illustrative modelling of *student retention* in this thesis I now discuss how complexity thinking has the distinct potential to be able to generate new insightful knowledge about effects in a complex system

[1] Thinking that is derived from complexity theory.

of *student retention* that is contextualized in Higher Education Physics and Engineering. In so doing, I will present three themes that are arguably of particular interest for both future research and practice. These themes are:

A complex system perspective,
the structures and dynamics of complex systems of student retention
and, *different levels of analysis.*

The first theme: The importance of employing a complex system perspective

The first theme is about the components in the models created for the students' self-reported experiences, their social and academic network, and their supportive systems. All of these affect each other in a nested, interacting way. Thus, they can be portrayed as giving rise to one another in an intricate way. Therefore, both research and action designed to mediate *student retention* should arguably take into account that each system of interest is composed of other smaller complex systems, and also, is a part of larger complex systems.

This means that relatively "simple" solutions, such as designing retention programmes using previous grades as the most important predictor for *student retention* have little chance of being effective. These advocates of design should work from a viewpoint that sees grades as being a possible contributing indicator for something else besides revealing an assimilated content knowledge. Otherwise, for example, such a deficit in complexity thinking could lead to the advocacy of an extra-curricular activity aimed at providing students with the knowledge that they are taken to “lack”, while the actual problem is embedded in a quite different setting.

The lack of a complex system perspective could potentially serve as an explanation for some of the critique that previous student modelling efforts, such as the Student Integration Model and the Student Attrition Model, have had when conflicting empirical findings emerge (for example, see Braxton, 2000). My exemplar use of a complex system of *student retention* to frame student retention research now opens the way for me to argue for the complex interaction between the different constructs of the previous models, and to suggest an explanation for how the differences in empirical findings can occur through the non-linearity of the interaction.

When I reflect on what practical implications arise from my thesis work, it becomes apparent to me that institutional actions to enhance *student retention* should be employing a complex system perspective. At the same time this perspective should also take into account the earlier findings of student retention research.

The second theme: Importance of the structure and dynamics of complex systems of student retention

The second theme of importance in my work is centred on the interaction of the components of a complex system (students, attitudes, experiences, and supportive systems). Through such interaction emergence, such as *student retention*, *academic achievement* and course completion, would take place. From my work, I argue that there is a need to direct the focus of research and practice into enhancing *student retention* towards recognizing that every component interaction can affect a complex system and its emergence as a whole.

I have argued that gaining greater insights into the emergence of the structures and dynamics of a complex system of *student retention* should be considered an integral part of student retention research in physics and engineering. From the modelling of the complex systems, one can theorize that the emergence of student behaviours, such as *student persistence* and *student retention*, could be traced back to the structures and dynamics of a complex system of *student retention*.

My work suggests that university staff should be made aware that complex structures and dynamics, (for example, in student experiences [Paper I], social and academic networks in a course or within a programme [Paper II], and students' supportive systems [Paper III]), can have give rise to emergent phenomena. In other words, only considering the students' academic aptitude and content learning to be in focus when students are progressing towards a degree in physics or engineering, must have severely limited possibilities.

The third theme: The importance of taking different levels of analysis into account

The importance of using different levels of analysis arose from the studies that I presented earlier in Chapter Three. Researchers and practitioners do not only need to take the individual students and a complex system of *student retention* into account in their thinking, but they also need to appreciate that *student retention* is affected by a number of nested levels within a larger complex system. Furthermore, it is important to acknowledge that educational structures in Higher Education Physics and Engineering are coevolving at different levels for all the students who are within the educational system.

In the example provided in Chapter Three, I modelled a contour of a complex system of *student retention* in terms of four nested systems. Researchers and practitioners need to appreciate what level of a system it is that they are proposing to work with and how this may relate to the other sub-systems that make up the complex system of *student retention*. Without such appreciation, choosing methods to best potentially maximize outcomes is impossible.

5. Direction of Future Work

"The future is the shape of things to come."

— H.G. Wells

Introduction

In this Chapter I put forward possible ways that I see my research project progressing. I envisage the main focus for the next part of my research to produce a comprehensive complex model of *student retention* based on good empirical data.

I also aim to focus on the possibilities of the usage of complexity thinking, and how it could strengthen both my research and the use of complexity thinking in student retention research. Finally, I provide sketches on other research directions which could present new directions for my research.

Steps toward crafting a better contour of a complex system of student retention

The central aim in this thesis has been to exemplify the use of complexity thinking in a student retention research setting in order to illustrate how the proposed research grounding of this thesis could lead to the crafting of a contour of a complex system of *student retention*. The following points need to be addressed to further the research into a complex model of *student retention* to facilitate the generation of a new model of *student retention* through an application of complexity thinking.

Improving the questionnaire

To exemplify the modelling of a contour of a complex system of *student retention* in this thesis, I used a subset of questions of a larger survey (Cabrera et al., 1992) with a limited sample. To improve this, a much better data set is envisioned. For example, one way of improving the questionnaire would be to use the full questionnaire used by Cabrera et al., 1992). This would enhance the reliability and validity status of the research instrument. It would also increase the number and range of questions for my data set. By increasing the number of questions, I will also increase the number of components in the modelled system.

Furthermore, there is a need to validate the questionnaire, thusly creating a questionnaire that can be used not only in a Swedish research context.

Improving the methodology

As of now, the method used to create networks out of similarities can be said to share aspects with Pathfinder network analysis (for example, see Schvaneveldt, 1990). In my analysis so far, the *similarities* have been analyzed locally and judged by the whole system's *connectedness* and *degree distribution*. In Pathfinder network analysis (Schvaneveldt, 1990) the *similarities* would be individually analyzed and the connections made would be judged by *a cost function*[1]. There is a need to fully explore the possible benefits to incorporate both the *cost function* of each connection made from pathfinder network analysis, and to judge the system by its *global degree distibution*.

Improving the quality of the sample

To enable a better crafting of a complex model, I am going to further ratify the reliability and validity of the questionnaire that I am using. I am also going to have a much larger and comprehensive data set to work with. This will enable me to generate generalizability with appropriate significance. For example, generally speaking, to allow for 95% significance on a confidence interval of 3%, to make a statistically validated model, I would need to survey around 900-1100 students, across a number of universities that share important characteristics of their educational environment.

[1] The cost function calculates the cost (in distance) to connect to every other node. This to try to minimize the number of *incorrect* links between nodes.

What can be done?

The most important aspect of what I could do with a reliable and validated questionnaire together with a sufficient sample size would be that I would be able to carry out regression analysis of the *degree distribution* in the contour of a complex system of *student retention* components to best fit a power-law distribution (a critical feature of a complex system).

If I can show that the distribution of a created networked model is power law distributed, then this will give me the possibility to argue that the model is truly *scale-free*, *nested,* and *complex*. As I see it, this is at the core the first step towards building a comprehensive, complex model of *student retention* in Higher Education Physics and Engineering.

Furthermore, it would be possible to define and understand context-specific constructs, i.e., how, for example, *faculty support* seems to be connected in the network, thus having the tools to define and understand these constructs in a new, empirically stronger way.

Social and academic systems

In Paper II, I set out to find structural differences in social and academic networks, and argue that it implies that a *social system* and an *academic system* (Spady, 1961; 1962; Tinto, 1987) exists, and the differences in the structure of both networks are connected with the governing *social system* and *academic system*.

To reach more than an implication of the existence of the *social system* and the *academic system*, I have previously argued that the sample size would need to be appropriately increased. In doing so, my research methodology would be streamlined making it possible to survey the around 100 classes I need to survey. (I am assuming that the structures of the social and academic networks differ more than 10%).

This would allow for a stronger argument to be created that there indeed are differences in the structure and dynamics of social and academic networks. It would also allow me to explore the effect that the previous theoretical constructs of earlier models on students in Higher Education Physics and Engineering may have from a complexity thinking perspective.

Students' supportive networks

To extend the poster about the supportive networks of students towards a networked model of students' supportive systems (i.e., Paper III) it will be necessary to do two complimentary studies.

Firstly, there is a need to do a larger pilot study to reach saturation in the formulation of the supportive categories for the different supportive functions that a student of Higher Education Physics or Engineering might have.

Secondly, I would use the refined categories of *supportive functions* to develop a supportive network questionnaire.

After the two studies are conducted, I would use the methodology described in my thesis to create an aggregated network map of the supportive networks of students in Higher Education Physics and Engineering. (This could include bringing in analytic constructs of agency and self-efficacy).

This work would allow practitioners to direct efforts towards getting students to find particular *enabling* supportive functions, to allow for, hopefully, a more rapidly evolving and expanding supportive network.

6. Post Thesis Reflection

"…crude classifications and false generalisations are the curse of all organised human life"

— H.G. Wells

A critical discussion

Now as I finalize my thesis, while contemplating the next stages of my PhD work, I find myself being able to critically review what I have done so far. Thus, I would like to include some discussion on the parts that I judge to be most critical, and feel that these lay in the area of my network analysis.

Firstly, the analysis method used to create a network ended up with a network with a very low maximum path length. Thus, the network that I formulated could unwittingly have incorporated some unknown inappropriate links. In a network, each pair of nodes is correlated in some way, and the analysis method needs to be refined in such a way that only connections that would be critical to the network are considered. For example, connections that are too far away in connectedness should be excluded so that no neighbouring nodes are included that have an overlap in connectedness.

What is currently lacking in the discussion is a critique of what the connections represent in the created network. This is mainly because this aspect lies in what I am still going to be doing – the next step in my research project. My position is that before I have a sufficiently adequate sample size to work with, going into detail about each of my connections cannot be meaningful.

However, even though the created network is small, I did use the centrality measurements that are usually used when the information is too large to generate a pictorial summary. I did this only to make the following illustrative point: it is possible to do these kinds of analyses when the questionnaire and sample size are theoretically robust enough to be judged to be sufficiently adequate to generate quality analysis.

I could also have discussed what the structural differences in the created networks are in relation to differences between students with high *academic achievement* in comparison to students with low *academic achievement*, and the nature of the casual relationship between components in a network. However, attending to this also forms part of my proposed "next steps" in my research.

How will I then go about looking into the pathways of students in Higher Education Physics and Engineering? One interesting approach I propose is to establish a longitudinal study that identifies students' "states" and investigates how different students move between these and what pathways lead to *student retention* or *student attrition*.

Finally, and perhaps most significantly for me, the work in this thesis has brought in a new way to interpret networks for the thorny issue of student retention. In this modelling, connection between two nodes is turning out to mean something different to other connections between other pairs. The details of that being still to emerge as I continue with my work in the area of student retention.

Concluding remarks

I would like to end this thesis by capturing the abiding commitment that the research work that I have reported on for my thesis has generated for me:

> We should take care of students while we can, continuously, individually and on different system levels, through employing a better and more complex understanding of their experiences as a student in higher education vis-à-vis choices taken in the context of their studies.

Acknowledgements

As my own research shows, I together with everyone around me made this thesis possible. I want to give special thanks to my supervisor Cedric Linder and to my co-supervisor Staffan Andersson for all, and how, they have contributed to my personal growth in intellectual thinking, research practices, and scholarship, and for all their help with the finalization of this thesis. I also want to thank my colleagues at the Division of Physics Education Research, Anne Linder, John Airey, Tobias Fredlund, Jannica Andersson-Chronholm, and Johan Larsson for all their support, especially the time that they gave me inspirational and insightful discussions. I would especially want to thank Anne Linder for her untiring and excellent editorial suggestions and language corrections that she made for my thesis and my research articles. Finally, I want to express my gratitude to visiting professors Rachel Moll and Duncan Fraser. Rachel opened my worldview into complexity thinking in a most profound way, and Duncan, at a most critical time, was able to patiently and carefully help me a great deal with important aspects of my methodological appreciation. I want to thank Maria Hamrin for all her support when I was visiting Umeå University. Furthermore, I would like to thank Margareta Enghag for all her help in introducing me to the fun and exiting the world of physics education research.

Then on a personal level I would also like to give a very special thanks and express a deep appreciation to my family: my partner, Jenny Brandt-Eriksson who has so unselfishly supported and motivated me throughout my Ph. D. Studies, and my son Adrian Theodor Forsman Eriksson, who started filling our lives with so much joy and meaning after making his appearance in early 2010.

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APPENDIX I

Ethical consent for questionnaire participation

Denna enkätundersökning syftar till att kartlägga studenters upplevelser av programstudier och att undersöka modeller för studentavhopp från universitetsstudier genom att undersöka viktiga faktorer som uppkommit genom tidigare forskning. Denna enkätundersökning är helt frivillig och du väljer själv efter du har fyllt i denna enkät om du vill lämna in ditt svar eller inte. När du lämnar in denna enkät, samtycker du att den information du lämnat kan användas i forskningssyfte, men endast av de som är en del av forskningsgruppen. Uppgifter som kan knytas till dig (ditt namn) kommer endast att behandlas av de som är involverade i forskningsgruppen och kommer inte att spridas till andra parter. All information kommer att avkodas för att skydda dina uppgifter. Du kan välja att medverka anonymt, men det är då viktigt att du anger det program du studerar.

Paper I

- A New Approach to Modelling Student Retention Through an Application of Complexity Thinking.

Forsman, J., Linder, C., Andersson, S., Moll, R. and Fraser, D. (revised). A New Approach to Modelling Studentsô Retention Through an Application of Complexity Thinking. Studies in Higher Education.

A New Approach to Modelling Student Retention Through an Application of Complexity Thinking

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Abstract: Complexity thinking is relatively new to education research and has rarely been used to examine complex issues in physics and engineering education. Issues in higher education such as student retention have been approached from a multiplicity of perspectives and are recognized as complex. The complex system of student retention modelling in higher education was examined to provide an illustrative account of the application of complexity thinking in such education research. Exemplar data was collected from undergraduate physics and related engineering students studying at a highly regarded traditional Swedish university. The analysis shows how complexity thinking may open up new ways of viewing and analysing complex educational issues in higher education in terms of nested, interdependent and interconnected systems. The analysis is not intended to present new findings in student retention, however, multidimensional scaling and network theory are used to illustrate the visualization of a possible representation of the system of items related to student retention and how to identify influential items.

Keywords: student retention; modelling systems; complexity thinking

Introduction and Research Aim

Complexity thinking, which is derived from complexity theory, is a powerful conceptual framework in education that draws on the qualities of complex systems to characterize learning systems (e.g., Davis and Sumara 2006). As such, with its organic, non-linear, relational and holistic features, complexity thinking presents a stark point of departure for contemporary educational research thinking (Morrison 2006). Thus, its application in education research is still relatively rare, particularly in higher education contexts, and a variety of good exemplars are hard to find for newcomers contemplating the use of complexity thinking as a conceptual framework. This article uses the field of student retention to provide such an exemplar.

When using complexity thinking, qualities such as decentralized network structure and short-range communication between agents can be seen to facilitate emergence of order in seemingly chaotic complex systems. Student retention is a complex system comprised of variables such as curriculum, financial and social supports where learning entails developing a sense of belonging and a desire to continue and complete a program (cf. Bean 2005; Tinto 2010; and see examples in Braxton 2000). Thus, we would argue that complexity thinking, as a trans-disciplinary perspective, is ideal for student retention modelling. Complexity thinking explicitly recognizes the connectedness and interactions between the multitude of variables that are currently recognized as influential to student retention (for example, see Bean 1982; and Tinto 1997). Our aim in this article is to illustratively explore the potential advantages of applying complexity thinking by bringing in exploratory factor analysis and multidimensional scaling to explore the problematic issue of student retention. Specifically we hope to illustrate how complexity thinking may be able to identify emerging structures and dynamics such as the adaptive and decentralized system of variables that influence student retention in higher education.

To achieve this aim we have used exemplar data consisting of retention questionnaire responses completed by Swedish first year physics and related engineering students. This particular context was chosen because currently engineers and scientists are in demand (for example, see European Commission 2004; Committee on Science, Engineering, and Public Policy 2007), while poor retention rates are also an international issue (see, for example Statistics Sweden and National Agency for Higher Education 2003, 2005, 2007, 2009, 2010). This is a complex context for applying student retention models that have been developed in the literature.

The data set was not selected in a way aimed at producing new variables needed for modelling student retention, but to provide a theoretical and illustrative account of the application of complexity thinking.

Historical overview of models of student retention

We have made a case for using an illustrative student retention data set, and to proceed a summative historical overview of models of student retention is needed. Readers who want a more extensive overview are directed to Summerskill (1962), Tinto (1975), Braxton (2000) and Metz (2004).

Throughout the history of building insightful models of student retention, the notion of *complexity*1 has been apparent, but it has not been brought to the fore in previous model designs. For example, Spady (1971, 38) argues that the formulation of a truly comprehensive model of student retention needs a perspective that 'regards the decision to leave a particular social system [studies in higher education] as the result of a complex social process'. More recently Bean (2005, 238) has argued that 'students' experiences are complex, and their reasons for departure are complex'. There are many other examples, see Spady (1970, 1971), Cabrera, Nora, and Castañeda (1993), Tinto (2010), Yorke and Longden (2004), and Barnett (2007).

This brings us to our starting point for the theoretical development for this study. Currently there are two models of student retention that are widely used: The Student Integration Model (Tinto 1975, 1987, 1997) and The Student Attrition Model (Bean 1980, 1982). While these models are seen by some researchers as being two separate, and even independent systems, we concur with Cabrera et al. (1992, 145) that both 'regard persistence [retention] as the result of a complex set of interactions over time.'

Yorke and Longden (2004) describe how the focus of early studies of student retention in higher education were on university structures, for example, libraries, schedules, courses, or examination timetables. Thereafter began a shift in modelling student retention towards incorporating a social

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[1] Complexity should not be seen as a synonym for 'complicated', but rather as a kind of 'generative metaphor' (Schön 1983) that extends a characterization of 'a complex unity that is capable of adapting itself to the sorts of new and diverse circumstances that an active agent is likely to encounter in a dynamic world' (Davis and Sumara 2006, 14).

integration perspective, influenced largely by the work of Spady (e.g., Spady 1970, 1971).

According to the social integration perspective, becoming integrated within a social system requires learning the norms, value-systems, and beliefs through interactions within the system. The social integration perspective played a major role in the development of Spady's theoretical model (Spady 1970, 1971); students needed to become a part of the social world of the university if the departure rates were to decline. In this model, social integration is a process that encompasses many aspects of students' everyday lives. This includes friendships, family support, the students' feeling of satisfaction and intellectual development, and so forth. Spady's model also included student characteristics such as grade performance, family background, and academic potential.

The social integration perspective gained momentum in student retention research through its potential for informing students' and universities' actions toward working to retain more students. Tinto (1975) published an expanded version of Spady's model. Tinto made a distinction between the social system of the university and the academic system, and argued that students also need to become academically integrated to persist in their studies. He posited that some interactions that lead to social integration, for example, making friends with fellow students, do not necessarily lead towards integration into the academic system of the university. The academic system, according to Tinto's (1975) conceptual framework, contains the academic rules, norms and expectations that govern academic interaction within the given institutional context.

During the early 1980s, researchers in the field empirically tested Tinto's constructs, and found that many of them were indeed impacting student retention. At this time, Bean, drawing on a psychological background, critiqued Tinto's model for its lack of external factors – such as economy and housing (Bean 1980). The point of departure for Bean's (1980) model was that student attrition should be seen as analogous to work turn-over in a traditional employment setting. Factors such as social experiences, the experience of the quality of the university, and family approval shape students' attitudes and behaviour within the university context.

To evaluate Bean's and Tinto's models, Cabrera et al. (1992) surveyed 2453 full-time American freshman students. Their findings indicate that the two student retention models have common ground and that they support each other in explanatory value. The questionnaire they designed was made up of 79 items, selected from well-validated instruments previously used in the field of student retention (for example, see Bean 1982, Pascarella and Terenzini 1979).

Later, Eaton and Bean (1995) theorized that students' experiences shape their individual behavioural approaches towards university life. This development expanded their earlier model of student attrition by adding approach and avoidance behavioural theory. Thus some students' experiences lead towards avoidance behaviour, and some towards an approach behaviour, both of which affect academic integration and thus the students' intention to leave or stay.

Tinto (1997) then undertook a case study that led him to expand his model by introducing the notion of 'internal' and 'external' communities that affect student integration into the social and academic systems of the university. He asserted that within classrooms there are 'internal' learning communities where both social and academic systems coexist. Through the concept of learning communities, together with the presence of 'external' communities, new constructs became available that could empower teachers who wanted to improve student retention (Tinto 1997).

After the development of Bean's and Tinto's models, Braxton's contribution to the field has led to a wide recognition of the range of variations within the empirical findings associated with Tinto's model and that it should be 'seriously revised' (Braxton 2000, 258). Braxton and Lien (2000) compiled empirical results on academic integration and concluded that Tinto's claim (1975, 1997) that it is a central construct has yet to be demonstrated empirically. The social integration piece of Tinto's theory has also been examined. Braxton and Hirshy (2004) provided empirical data to support their proposal to incorporate three additional factors that may influence social integration: commitment of the institution to student welfare, institutional integrity, and communal potential. Braxton (2000) suggested that a new foundation for such a modelling system needs to be developed and Tinto (2010) himself argued for the need to develop models that aim towards informing the institutional action of universities.

The next step is then to put forward a modelling system that can adapt to variations within empirical findings, has the ability to harbour constructs of the earlier models, and empowers universities in their actions toward enhancing student retention. The conceptual framework of this article, complexity thinking, is a perspective that can help achieve these aims and has the potential to suggest changes to educational practice.

Conceptual framework

In this section, we will present the concepts that we draw upon from complexity thinking that illustrate the connected, adaptive, and dynamic nature of the complex system of student retention in higher education. At the same time this illustration can be seen to exemplify how drawing on complexity thinking can allow for the generation of a more powerful and holistic modelling system of student retention. To do this we use exploratory factor analysis, multidimensional scaling, and network theory.

Complexity thinking

Complexity thinking aims to describe and understand complex systems and their capacity to show order, patterns, and structure. Especially important is how these orders, patterns and structures seem to emerge spontaneously from interactions between components of systems. Complexity thinking has emerged and taken root in a wide range of disciplines, generating a theory that essentially 'transcends disciplines' (Waldrop 1992). For more details on the historical development of complexity thinking, see Waldrop (1992), and for an overview of current applications of complexity thinking in a wide array of fields, see Mitchell (2009).

Complexity thinking is often pitted against 'classical science', which is, in turn, portrayed in terms of efforts to condense phenomena into their simplest components. However, to obtain a reasonable portrayal of a complex phenomenon, an understanding of the properties of the components alone is not sufficient. Thus, what is central in describing or understanding a complex system is identifying the components, their interactions, and what *emerges* from the complex system: system behaviours, properties and structures, or the 'structuring structures' (Bourdieu 1984) of the complex system (for example, see Davis and Sumara 2006).

One can conceptualize the essential aspects of a complex system's structure, dynamics, and predictability through metaphors (for example, see

Gilstrap 2005), computer simulations (for example, see Brown and Eisenhardt 1997) and systems of modelling (for example, see Mowat and Davis 2010). From this perspective, the essential aspect of complex systems, and what has given rise to complexity thinking's ubiquitous emergence, is that all complex systems share similar structure and dynamics. The behaviour of complex systems, such as society, organisms, or the Internet can only be conceptually discussed as somewhere in-between complete order and complete disorder. Any attempt to measure or distinguish one system as more complex than another often breaks down (Mitchell 2009). If a system is to be identified as being a complex system what needs to be investigated are the characteristic structures and dynamics that are common among complex systems, not the complexity itself (Davis and Sumara 2006).

The structure of complex systems

Complex systems have *decentralized networked structure*, which means that there are a few components or nodes that are much more connected than others. This kind of structure can be contrast to two other types of networks: (1) centralized networks with only one central node that every other node is connected to; and, (2) distributed networks where all nodes have the same connectivity in the network. Information is spread efficiently in centralized networks, but they are vulnerable to break down due to the dependency on the central node. On the other hand, distributed networks are robust but inefficient in spreading information. In decentralized networks when a highly connected component is removed or breaks down, the whole system will suffer considerable damage. A decentralized system will remain stable, however, with the removal of any of the many less important or less connected nodes.

Due to their decentralized structure, all complex systems are *networked* with other complex systems. Moreover, components within a complex system can be considered to be complex systems themselves, thus complex systems are *nested*. Nested systems have similar structure and dynamics but operate on different scales (time, size and so forth). For example, mathematics learning-for-teaching has been modelled as several nested systems: subjective understanding, classroom collectivity, curriculum structure, and mathematical objects (Davis and Simmt 2006). Each level of such nested complex systems exhibits similar structures and dynamics, but operates within different time-scales (for example, subjective understanding has a faster rate of change than mathematical objects) and represents a different level of analysis (such as the level of an individual, the level of a group of individuals, or the level of a particular culture).

Dynamics of complex systems

One key aspect of complex systems is that they are continually changing as the components in the system interact with the external environment and with one another. This means that complex systems are *adaptive* and *self-organizing*; properties, behaviour and structure all emerge without an external system or an internal 'leader system' that controls the complex system.

Components of complex systems interact mainly locally via *neighbour-interactions*, which can fuel processes that lead to emergence such as positive feedback (brings the system to a non-equilibrium state) or negative feedback to maintain equilibrium. Positive feedback tends to amplify, and negative feedback tends to dampen properties, behaviours and structures. Depending on how 'connected' each component is with other components within the system, the positive feedback can give rise to the possibility of *emergence*.

Complexity thinking has established that decentralized network structure is a key element in facilitating emergence in complex systems. Through the concept of neighbour-interactions and the decentralized network structure we can argue that nested systems that are highly connected can be seen as close to each other (Davis and Sumara 2006).

Complexity thinking is not characterized by a particular method, but by a methodological perspective that employs a range of methods to study complex phenomena (Davis and Sumara 2006). Complex systems are networked constellations of components, which in our example are the students' viewpoints of their experience of higher education in the first year. Each item in our analysis, such as students' attitudes towards their program and their financial stability, is considered to emerge from and be situated within multiple complex systems. From here a formulation of a possible visualization of the structure and dynamics of the complex system of students' retention is created through the use of the following tools that can be seen to be complimentary to those used in complexity studies: exploratory factor analysis, multidimensional scaling, and network theory.

Exploratory factor analysis

Exploratory factor analysis is used to study patterns and order within complex data by comparing angles between points in a multidimensional space. A useful way to view exploratory factor analysis is to see it as essentially what Hoftstede et al. (1990, 299) has called 'ecological factor analysis'; an analysis where the stability of the analysis does '…not depend on the number of aggregate cases but on the number of independent individuals who contributed to each case'.

The items used in the analysis are the retention questionnaire responses plus other student-specific information. Exploratory factor analysis identifies those items that have ‘commonalities’ (Kim and Mueller 1978) by using the covariance between the items. Items with higher covariance are grouped into a number of factors, with the number being determined by the groupings that arise. Using a complexity thinking perspective, these factors were interpreted as a self-organized pattern of nested systems that make up the complex system of student retention in higher education.

Exploratory factor analysis will normally reveal that some of the items are present in more than one of the factors. This was interpreted as evidence of interactions between the nested systems through their shared items.

Multidimensional scaling

As denoted by the conceptual framework, components of a complex system interact locally (Davis and Sumara 2006) and thus components that have a high relative closeness to other components in the multidimensional scaling analysis can be regarded as being *connected*[2] and within each other's *zone of influence*. In the multidimensional scaling analysis of the questionnaire data, the answers and their proximities are used to create a representation of the emergent network structure of the complex system. The items may be seen as vertices connected by edges, which form a basis for visualization and allow for measurements of item interaction through the use of network theory.

A good way to determine the relative proximity of items to one another is to use multidimensional scaling because it offers a way to calculate the distances between points of data in multidimensional space. The relative

[2] ‘Connected’ is used as a broad term that encompasses the interaction, communication, and dependence between the different components of the system.

closeness ('multidimensional proximity') of items to one another is the 'likeness' or 'similarity' (Schiffman et al. 1981) of those items.

Network theory

The orienting emphasis in network theory is 'structural relations' (Knocke and Yang 2008). From such a framing the essential elements of a network are the nodes (vertices) and the links (edges) between nodes. In the current study, nodes are items examined in the retention questionnaire and student-record data. Network theory is thus a powerful analytic tool to explore and illustrate the connectivity of the structure produced by the multidimensional scaling.

Network theory concepts

The *nodes* represent the components of a network (i.e. items on the retention questionnaire and student-record data), and the edges represent the relationships between the nodes. When two nodes are directly connected the two nodes are said to be adjacent. A *path* is a way through a sequence of nodes that begins with a starting node, follows adjacent nodes through the network and ends at an ending node. When every node in the network is reachable (i.e. a path exists between every node) the network is connected. If there are many paths between two nodes, the *shortest path* between them is the one with the fewest connections made through other nodes (Freeman 1978). Visualization and analysis of networks, and therefore complex systems, is made possible by using these constructs of network theory.

Network measurements and interpretation

The network to represent the system of student retention was formed using multidimensional scaling. As in the literature, we assumed that we had an undirected network where the connections between the nodes did not have a specific direction of influence. Analysis of the created network was done by using Statnet (Handcock et al. 2003), a free package designed for analysing networks which employs the "R" statistical computing and graphics program. Identification of 'important' nodes was done by analysing each node's *betweenness centrality* and *closeness centrality*.

In this study we distinguish between *closeness centrality* and *betweenness centrality* (Bernhardsson 2009). Closeness centrality is an ordinal measure of how 'close' every other node is, and it is calculated through finding the shortest path between nodes. Information can be spread to the whole network more efficiently from nodes with high closeness centrality (Freeman 1978). Betweenness centrality is the frequency that one particular node is a part of the shortest path between every other node. Nodes that are more frequently a part of the shortest path between nodes may be interpreted as having a high degree of '*control* of communication' (Freeman 1978, 224) in the network.

Method

The exemplar data was collected from two sources: student-records were used to obtain student demographic information items such as Age, Gender, Retention, and Higher Education Credits achieved within (HECwP) and outside (HECoP) the programme. Thereafter, a questionnaire was developed to explore influences on student retention.

Retention questionnaire

To generate data that we felt would well serve our research aim we chose the following setting: a typical first year physics course at a highly regarded traditional Swedish university (most of the students enrolled were in an engineering programme). For our data collection a questionnaire was constructed, based on previous student retention research and physics education research. In particular the questions that provide the highest explanatory value in Cabrera et al.'s (1992) survey of the convergence of the Student Integration Model (Tinto 1975, 1987, 1997) and the Student Attrition Model (Bean 1980, 1982) were used and some questions were added. See Appendix 1 for the detailed source(s) for each question, plus a detailed motivation for questions that were changed or added. Students answering the questionnaire were asked to mark their level of agreement (or disagreement) with 29 statements on a five-point Likert scale.

To get a good questionnaire-completion response rate we chose a venue that allowed us to easily give a motivating and thorough discussion of our aims and the associated ethical considerations we would uphold. Most (51) students agreed to participate and the questionnaire was administered towards the end of their first year (second semester) of university study in 2009. Thirty-two of the participating students were registered in a four and a half year Master of Science in Engineering (Physics) programme, twelve were registered in a three year Bachelor of Science (Physics) programme and the remaining seven were registered in a four and a half year Master of Science in Engineering (Materials Physics) programme. Re-enrolment in the second year (third semester) was used as a measurement of student retention and was found to be 82.4%.

Illustrative results

Exploratory factor analysis

Having satisfied ourselves that we had data items grounded in the literature, we started with an exploratory factor analysis. This was to identify the nested complex systems that make up the greater system of student retention through the identification of the factors of the overall system. Our analytical tool was the Statistical Package for the Social Sciences, SPSS (Predictive Analytic SoftWare, PASW, version 18.0). Our starting point was the normalized matrix of the questionnaire data together with the students' higher education credits achieved within and outside their programme, retention (re-enrolment in the second year), age, and gender.

The following three measures were used together to achieve an appropriate correlation matrix of items to be used for exploratory factor analysis (Dziuban and Shirkey 1974):

1. Kaiser-Meyer-Olkin's (KMO) measure of sampling adequacy. Items were removed recursively from the data until a value of 0.68 was obtained, close to the guideline 0.7 recommended by Kaiser and Rice (1974).
2. Bartlett's (1950) test of sphericity. This had a significance level of less than 0.001 when guideline 1 had been achieved.
3. The anti-image correlation measure of sampling adequacy (MSA). Items with an MSA less than 0.5 were removed (Kaiser 1970).

As a result, eleven items were removed and are listed in Table 1. These items were interpreted as having little effect on the system of student retention, at least as far as this illustrative study is concerned, given the limited data set and the high level of retention from first year to second year.

Question No	Item
-	Age
-	Gender
-	Credits passed that are not a part of the programme of study
6	My possibility to continue with my studies is dependent on me working while I study
9	It is important for me to graduate at my University
13	I have achieved the study-results I expected during the first year
18	It is important for me to get a university degree
20	I have developed a good relationship with my teachers in the courses I have studied
26	First year physics courses have been inspiring
27	University physics courses are much different from my previous physics courses
28	First year physics courses have had a clear connection to everyday life

Table 1. Items removed from the exploratory factor analysis.

To decide the number of factors in the model we used a scree test (see scree plot in Figure 1). ‘The scree test involves examining the graph of the eigenvalues … and looking for the natural bend or break point in the data where the curve flattens out. The number of data points *above* the 'break' ... is usually the number of factors to retain’ (Costello 2005, 3). To generate the scree plot, every item is treated as a vector that has an eigenvalue (length) of 1.0, before the optimizations of the sum of the vector projections on factors are carried out. For example, from Figure 1 we can see that an eigenvalue of seven leads to a One Factor solution which provides us with the information that all significant loadings in One Factor can be grouped, providing us with 7 times as much information as a single variable. It also means that the items in the factor share traits.

This led us to choose a Four Factor solution for the model (Hofstede 2001). The cut-off at Four Factors, and not Five (although they have nearly the same eigenvalue) was guided by seeing that a Five Factor solution provided one factor with only two variables that had significant loading (more than 0.32), which according to the analysis-method is not appropriate for such a factor solution. The 'extra' factor would not give much more information than adding one or two other variables to the analysis or the questionnaire.

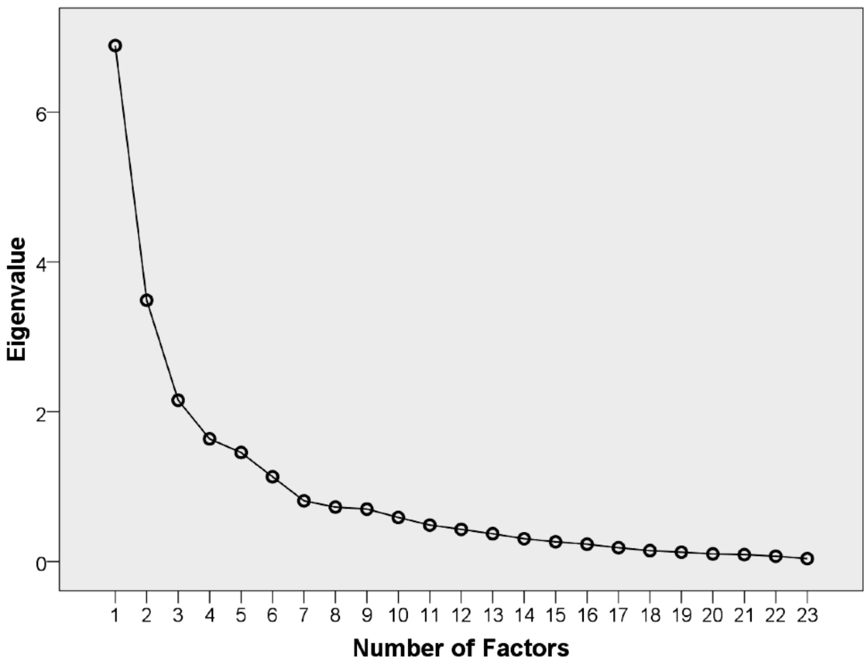

Figure 1. Scree plot showing eigenvalues and number of factors after rotation. A Four Factor solution was chosen.

Significant item loadings for each factor were identified (See Table 2) by using a minimum loading of 0.32 on each item, which corresponds to a 10%

shared variance between items (Tabachnick and Fidell 2001). Question 12 was retained at a loading of 0.313 (which is very close to 0.32).

The results of the exploratory factor analysis are shown in Table 2. Note that these results differ from the normal result in exploratory factor analysis where unique variables are sought for each factor. It is tempting to try to characterize the four factors (systems of components) in terms of the systems identified by others (such as university academic systems and social systems (Tinto 1975) and support systems (Bean 1980)) but this cannot be done because of the small sample size. What Table 2 does show is that there is an overlap of items between the four factors, each of which is a complex system in itself. This illustrates the complexity, the interdependence, and the nestedness of the system of student retention as a whole. It also highlights the existence of neighbour interactions between the four nested component systems, as well as the fact that they have fuzzy boundaries.

Our sample size is far too small to even attempt a tentative characterization of these four factors. A study using a sufficiently large enough sample size could characterize each factor according to the highest loading variables in that factor. *To illustrate how this could be done*, we generated the following factors from our data: Factor 1; the status of the programme the students are studying; Factor 2; the sense of belonging; Factor 3; retention; Factor 4: financial issues, and has particularly fuzzy boundaries with Factors 1 and 3.

Items	Factor 1	Factor 2	Factor 3	Factor 4
H.E. credits programme (HECwP)			0.542	
Retention			0.934	
Q1. Best university programme	0.788			
Q2. Family approval		0.472		
Q3. Satisfied with finances				0.836
Q4. Finances - focus on studies				0.833
Q5. Finances - teacher demands				0.796
Q7. Satisfied with curriculum	0.328	0.458		
Q8. Close friends encouragement		0.580		
Q10. I belong at my university		0.637	0.447	
Q11. Future employment	0.464	0.390		
Q12. My close friends rate this institution as high quality			0.313	
Q14. Satisfied with experience of higher education		0.687	0.411	
Q15. Easy to make new friends		0.842		
Q16. Right choice - university		0.683	0.399	
Q17. Right choice - programme	0.758			
Q19. It is important to get a degree from this programme	0.708			
Q21. Initiation weeks		0.855		
Q22. First year courses fit together				0.459
Q23. Previous knowledge		0.385		
Q24. Clear educational trajectory		0.447	0.396	
Q25. Faculty support		0.345	0.322	0.461
Q29. I intend to re-enroll	0.835			

Table 2. Loading from the exploratory factor analysis giving the factors sorted adjacently by the number of shared items. Light grey shading denotes the items that have a loading above 0.32 in more than one factor.

Multidimensional scaling

Multidimensional scaling was used to visualize the network of components that influence student retention, and network theory data analysis tools and complexity thinking were used to interpret the results.

Network creation

The multidimensional scaling analysis used the same data as the exploratory factor analysis to determine the distances between items. A dimensional solution ranging from two to four dimensions was explored, because multidimensional scaling usually provides a solution that has fewer dimensions than exploratory factor analysis on the same data (Schiffman et al. 1981).

To create a visualization of the network (Figure 2) we used the multidimensional proximities between items to identify items with relative closeness or proximity. Using the neighbour-interactions concept and an understanding of the structure of decentralized networks (Davis and Sumara 2006) from complexity thinking, we recursively lowered the cut-off for proximities, and network visualizations were produced. The statistical computing and graphics "R" program, together with the Statnet package (Handcock et al. 2003), was used for visualization and measurements. Iterations were run as long as the network continued to resemble a decentralized network, but were ended before the network broke down (after 15 iterations) and ceased to be connected (Freeman 1978). Two items were considered to be within each others' 'zone of influence' when their proximity was below 0.25. The analysis was complete when the majority of the items had proximities less than 0.25. To retain the connectedness of the system Retention needed to have a cut-off of 0.5. HECoP, Gender, Q6 (studies dependent on working) and Q9 (importance of achieving a degree from this university) all dropped out at this cut-off level. These items are four of the eleven items that were dropped from the exploratory factor analysis. However, not all items that were dropped in the exploratory factor analysis were only loosely connected in the network. Moreover, three items (nodes) that may be particularly influential were identified. These three items were each present in two of the four factors in the exploratory factor analysis.

Note that as the cut-off level is lowered further, the system becomes less and less connected. At a cut-off proximity of 0.1 less than half the items remain connected to one another and there are very few connections between them compared to Figure 2.

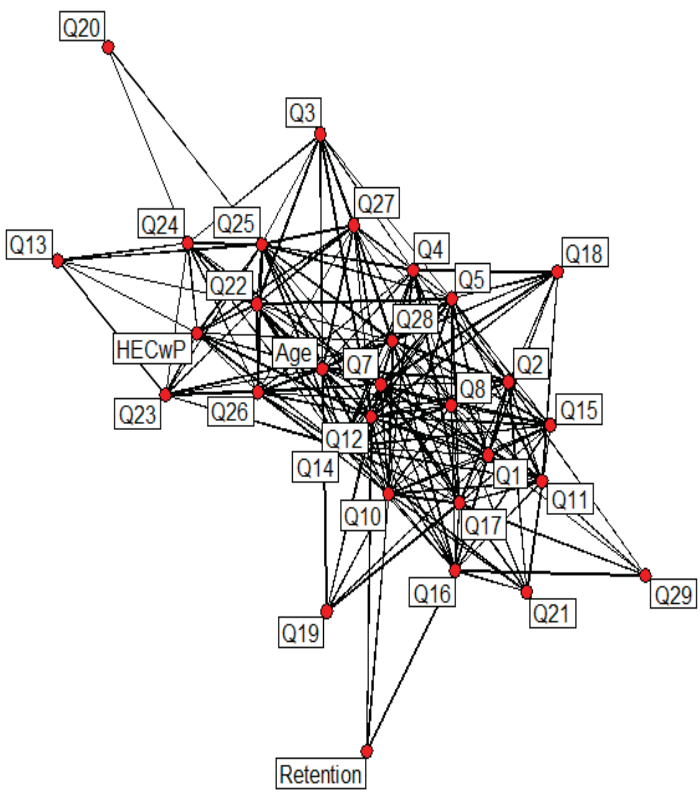

Figure 2. Network visualization from multidimensional scaling analysis. Note that this visualisation shows just the connections, not the actual proximities. HECwP is higher education credits achieved within the programme.

Influential items

Influential items in the system are interpreted as items which are highly connected to other items, as measured by closeness and betweenness centrality. These items either have short paths to other items (closeness) or have a tendency to be part of a short path (betweenness). Thus information passes through these nodes (or items) frequently and they are key to effective and efficient information sharing. In a decentralized complex system these items contribute to the connectedness of the system and the removal of one of them could lead to the collapse of the system.

We used the closeness centrality and betweenness centrality scatter plot (Figure 3) to identify network items (nodes) that have a large influence in the network. Nodes with high closeness centrality and high betweenness centrality both distribute information effectively to a large proportion of the system, and are in a position of 'control' of other nodes' influences on the system. Figure 3 shows nodes that are 'close' to other nodes and nodes which have a high frequency of being 'between' other nodes.

Consideration of Figure 3 shows that there are seven items with relatively high betweenness centrality as well as relatively high closeness centrality: Q12 (friends' opinion of institutional quality), Q7 (satisfaction with one's course curriculum), Q25 (faculty support), Age of the students, Q14 (students' satisfaction of being at the university), Q10 (the feeling of belonging at the university) and Q28 (physics is connected to everyday life). Item Q25 (faculty support) is interesting in that it seems to lie outside the broad band of points showing higher betweenness centrality vs higher closeness centrality: It has a much higher betweenness centrality than the rest of the items in the band. The same is also true for Q24 (clear educational trajectory). Connections between exploratory factor analysis results and multidimensional scaling results will be discussed below.

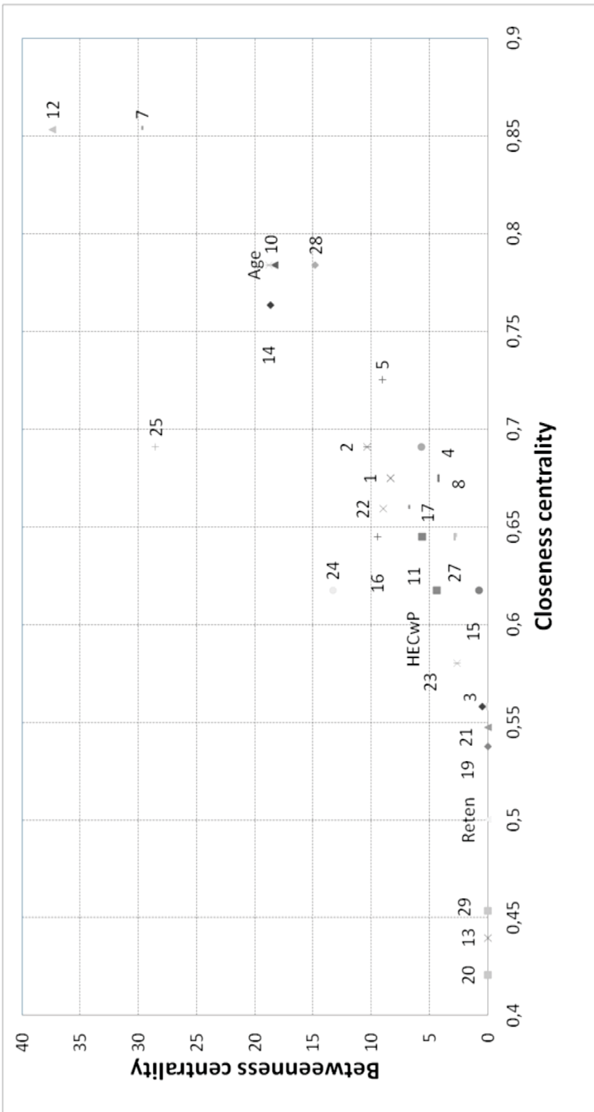

Figure 3.2: Closeness centrality and betweenness centrality scatter plot of the network created by the multidimensional scaling analysis proximities of items. All numbered markers corresponds to same number question. Marker "reten" corresponds to the measurement of student retention. Marker named "HECwP" corresponds to students' Higher Education Credits achieved Within Programme. Marker "Age" corresponds to the age of the studends.

Discussion

While not all aspects of a complex system such as student retention can be characterized by any research approach, we have tried to compellingly illustrate how bringing in a complexity thinking perspective can offer unique possibilities and interpretations. We have also attempted to show how complementary tools can be used in such studies. For example, our illustration drew on factor analysis to identify component complex systems within the broader complex system of student retention, and to demonstrate their nested and interdependent structure. In our example, four component systems emerged as a possible solution to the exploratory factor analysis and illustrated how a significant overlap, or fuzzy boundaries, between the systems may be interpreted in terms of the interdependence and interactions between systems and items within the systems that influence student retention. Items shared by multiple factors could be interpreted as key issues and may be areas that post secondary institutions may want to target with changes or efforts in order to improve student retention rates.

Multidimensional scaling was used to show the connectedness of items, to identify influential items and to visualize how the items of the complex system interact with one another. Complexity thinking provides new insights into student retention in terms of advocating for paying attention to items that have the potential to influence *the complex system as a whole.* This means that items should not be seen as direct linear influences, but mainly as *influencing* what takes place indirectly *through other items.* A stronger data set would allow for claims to be made about which items are more influential. Then targeted efforts to implement changes in the system of student retention could be made by manipulating particular (influential) items and the ensuing dynamics at several levels of analysis (or complex systems) could be observed and studied. With the identification of influential variables and a knowledge of the structure and dynamics of complex systems in general, targeted efforts could be made to positively influence the system as a whole.

Multidimensional scaling was chosen over other analysis techniques such as structural equation modelling and path analysis because these techniques rely on estimates of linear relations among a set of variables (Denison 1982). Multidimensional scaling techniques provide a non-linear approach to data analysis (Kaplan 2004). Using this idea we illustrated how a visual representation of the structure and dynamics of a complex system can be created.

What we were unable to illustrate with our current limited data set were issues relating to reliability and validity, however we feel that this has not detracted from our aim since the competent dealing with such issues can only be dealt with when an adequate data set has been obtained.

In conclusion, we believe that our illustrative analysis has managed to provide a credible example of a method of researching into complex issues in higher education which we believe has the potential to facilitate new, refreshing and exciting outcomes.

Acknowledgements

We thank the anonymous reviewers for their invaluable comments and suggestions that led to improving this article. We also thank Anne Linder and John Airey for their grammatical and logical comments, and Jannika Chronholm-Andersson for her developmental discussions, during the drafting of this article.

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Appendix 1: Questionnaire

The questionnaire is given in Table A1, together with the sources/motivations for each of the questions. It was constructed after extensive discussions with colleagues and senior students, to ensure that it was fitting for the Swedish higher education context. Fifteen questions were taken from the eighteen identified by Cabrera et al. (1992) as having high explanatory value for student retention. Three questions were omitted: the one about financial support was covered by three financial questions that were added (Questions 4-6); the question about transferring to other universities was omitted because it is not common in the Swedish context; and the third question about developing personal relationships was covered by Question 21 about the initiation weeks programme. Ten of the fifteen questions were modified slightly to fit the Swedish context; all fifteen questions were translated into Swedish and then independently translated back into English for a meaning-matching check and final translation adjustments.

Since Cabrera et al.'s survey was performed in 1992, other work was used to add fourteen questions to the questionnaire. Questions 1 and 17 were added to address students' programme of study. Questions 4 – 6 were added about students' financial attitudes. Questions 20, 23, and 25 were added to better explore the importance of teacher-student interactions. Question 21 was added to account for the tradition of initiation weeks that students have during their first weeks at the university. Questions 22 and 24 were added to explore how the students experience their courses as 'pieces of a whole' (Booth and Ingerman 2002). Questions 26 – 28 were included to ground the questionnaire in our context of undergraduate engineering and physics programmes.

Table A1. Questions asked and their source(s) and/or motivation (changes/new questions)

Question	Source/motivation
Q1. I am studying one of the best programmes at the university.	In Sweden, students in general choose "programmes" that are planned to lead towards a degree
Q2. My family approves of my attending my University.	Cabrera et al. (1992)
Q3. I am satisfied with my financial situation.	Cabrera et al. (1992), mod: In Sweden, University Education is free and students receive study loans and grants from the government towards living expenses.
Q4. My financial situation allows me to focus on my studies as much as I want.	Expansion of Question 3 - see Cabrera et al. 1993; Paulsen and St. John 1997
Q5. My financial situation allows me to focus on my studies as much as the teachers demands.	Expansion of Question 3 - see Cabrera et al. 1993; Paulsen and St. John 1997
Q6.My possibility to continue with my studies is dependent on me working while I study.	Expansion of Question 3 - see Cabrera et al. 1993; Paulsen and St. John 1997
Q7. I am satisfied with my course curriculum.	Cabrera et al. (1992)
Q8. My close friends encourage me to continue attending my University.	Cabrera et al. (1992)

Q9. It is very important for me to graduate at my University.	Cabrera et al. (1992) simplified
Q10. I feel I belong at my University.	Cabrera et al. (1992)
Q11. My degree at this university will help me secure future employment.	Cabrera et al. (1992)
Q12. My close friends rate this university as a high quality institution.	Cabrera et al. (1992)
Q13. I have achieved the study-results I expected during the first year.	Cabrera et al. (1992) modified
Q14. I am satisfied with my experience of H.E.	Cabrera et al. (1992) modified
Q15. It has been easy for me to meet and make friends with other students at this university.	Cabrera et al. (1992)
Q16. I am confident I made the right decision in choosing to attend at my university.	Cabrera et al. (1992)
Q17. I was right when choosing to study this programme.	New question
Q18. It is important for me to get a university degree.	Cabrera et al. (1992), terminology change
Q19. It is important for me to get a degree from this particular programme.	Cabrera et al. (1992), terminology change
Q20. I have developed a good relationship with my teachers in the courses I have studied.	See Spady 1970;1971; Tinto 1975;1987;1997, Terenzini and Pascarella 1980

Q21. The initiation weeks were a good start for my program studies.	New question to account for the traditional “introduction period” that students have during their first weeks at the university.
Q22. It is clear to me how the courses during the first year fit together.	See Booth and Ingerman 2002
Q23. The teaching has corresponded well with my previous knowledge.	See Spady 1970;1971; Tinto 1975;1987;1997, Terenzini and Pascarella 1980
Q24. My educational trajectory is clear for me.	See Booth and Ingerman 2002
Q25. Faculty staff have provided me with the support I needed to succeed in my studies.	See Spady 1970;1971; Tinto 1975;1987;1997, Terenzini and Pascarella 1980
Q26. First year physics courses have been inspiring.	See Lujan and DiCarlo 2006
Q27. University physics courses are much different from my previous physics courses.	See Tinto 1975; 1987; 1997
Q28. First year physics courses have had a clear connection to everyday life.	See Adams et al. 2006; Redish 2003
Q29. I will re-enrol at this programme of study next autumn.	New question

Paper II

– The emergence of social and academic networks: An exploratory study of complex structures and dynamics in students' social and academic networks

Presented as a poster for NARST (National Association for Research in Science Teaching) 2011 conference: Global Sustainability and Public Understanding of Science: The Role of Science Education Research in the International Community

THE EMERGENCE OF SOCIAL AND ACADEMIC NETWORKS: AN EXPLORATORY STUDY OF COMPLEX STRUCTURES AND DYNAMICS IN STUDENTS' SOCIAL AND ACADEMIC NETWORKS

A complexity thinking perspective and social analysis tools are used to direct research of student retention to explore what structures emerge from students' interactions with each other within their courses, in particular the social and academic networks they create. Particular focus is on how these structures of social and academic networks can be linked to students' grade performance and course completion. The analysis draws on a network survey and a retention questionnaire conducted at a highly regarded traditional Swedish university. Outcomes suggest that while the physics and engineering student participants (N=157) socialize and study together to a large degree, the structure and dynamics of the social and academic network seem to be influencing different parts of students' lives; the academic network had more in common with academic achievement than the social network of students.

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Introduction

The percentage of students within Higher Education Physics and Engineering programmes who successfully complete their degree within the designed time period is decreasing internationally (Organisation for Economic Cooperation and Development, 2009; Committee on Science, Engineering, and Public Policy, 2007). In Sweden, the percentage of students who graduate with a Bachelor of Engineering in Physics in the designed time period is only 63% of what it was fifteen years ago. In that time, the number of new entrants has grown by 50% (c.f. Statistics Sweden and National Agency for Higher Education, 2003, 2005, 2007, 2009, 2010). For higher education institutions in both the European Union and the United States there is a renewed challenge to create conditions where the students are more likely to continue with their studies and to work towards graduation, especially in science, engineering and technology oriented areas.

Previous research in student retention and persistence (for example, see Braxton, Vesper, & Hossler, 1995; Spady, 1971; Tinto, 1975, 1987, 1997) has identified integration into the universities' social and academic systems as an important factor that influences student retention and persistence. Integration into these systems has been theorized to shape students' shared group values, support structures and their sense of institutional commitment. These factors, in turn, have been shown to affect student retention (Bean, 1980, 1982).

The social and academic systems of the university, argued by Tinto (1975, 1987, 1997), are composed of constructs that govern social and academic interactions within the university such as expectations, values and norms. These encompass every part of a student's social and academic life while attending the university; making friendships, meeting new people and having obligations within a social group. These two systems "...appear as two nested spheres, where the academic occurs within the broader social system that pervades the campus" (Tinto, 1997, p.619). Thus students' integration into the university is dependent on *student* ↔ *student* and *student* ↔ *faculty* interactions (Tinto, 1987) and students' peers have been argued to be "the single most potent source of influence" (Astin, 1993, p. 398).

Our study focuses on the structure and dynamics of students' social and academic systems of their interactions within the university; in other words the networked nature of students' interactions. Our point of departure from earlier research is a complexity thinking perspective (Davis & Sumara, 2006), which informs our theoretical positioning: If interactions within the university are regulated by different governing principles originating from both social and academic systems, then differences in the networked structure or dynamics of those interactions should emerge to form two separate networks of students' interactions; a social network and an academic network. To explore this hypothesis our data pool consisted of a retention questionnaire, a network survey, and student records, for students in three separate courses in Bachelor of Engineering in Physics, Materials Engineering, Aquatic and Environmental Engineering, and Energy Systems Engineering programmes at a highly regarded Swedish university. Data was analyzed using a complexity thinking perspective (Davis & Sumara, 2006) and social network analysis tools in order to explore the following research questions:

1) What similarities and differences exist between social and academic networks of the participating students?
2) What educationally significant characteristics do these students' social and academic networks have?
3)

Background

For the purposes of this article, we are providing a brief overview of the field of student retention focusing on both the complex[1] phenomenon of student retention, as well as details of important constructs in contemporary student integration modelling; the social and academic systems of the university.

Student Retention Research

Historically, two strands of models for student retention can be identified: The Student Integration Model (Tinto, 1975, 1987, 1997) and The Student Attrition Model (Bean, 1980, 1982). The Student Integration Model and the Student Attrition Model can be seen as tenets in student retention research. However, Braxton (2000) argues that, due to the wide variations within empirical trials and findings associated with Tinto's model, it should be "seriously revised" (p. 258), and even suggests that a new foundation for such a model needs to be developed. While these models are seen by some researchers as being separate and distinct, we agree with Cabrera, Castañeda, Nora, and Hengstler (1992), that both models "regard persistence [retention] as the result of a complex set of interactions over time" (p. 145).

Throughout the history of student retention research (which expanded to encompass attrition, learning, achievement and progression) the notion of complexity has been apparent. For example, if the research in student retention is to be more fruitful it needs to take into account student decisions

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[1] Complex should not be seen as a synonym for "complicated", but rather as a kind of "generative metaphor" (Schön, 1983) that extends a characterization of "a complex unity that is capable of adapting itself to the sorts of new and diverse circumstances that an active agent is likely to encounter in a dynamic world" (Davis and Sumara, 2006, p.14).

to leave as "…a particular social system [studies in higher education] as the result of a complex social process" (Spady, 1971, p.38). More recently Bean (2005) has argued that "students' experiences are complex, and their reasons for departure are complex" (p. 238). Thus the application of complexity thinking and associated analysis tools in student retention research becomes a natural direction to extend current theorizing.

The Social and Academic Systems of the University

Within the students' *complex experience* of higher education, the idea of social and academic systems has been put forward (for example, see Spady, 1971; Tinto, 1975, 1987, 1997). The social and academic systems are composed of the rules, norms, values, and expectations that govern social and academic interactions within the university. Tinto theorized about how "social and academic life are interwoven and the ways in which social communities *emerge* out of academic activities that take place within the more limited academic sphere of the classroom, a sphere of activities that is necessarily also social in character" (1997, p.619).

Social and academic systems are interlinked in a complex way and Tinto (1975) has argued that in order to have a chance to continue their studies individuals need to be integrated into both of these systems. For students to become integrated into the social and academic systems, there is a need for the students and institutions to find common ground between the rules, norms, values and expectations of both the students and their institutions. Both social integration and academic integration occur mostly through informal peer group associations and interaction with faculty (Tinto, 1975, 1987, 1997). Students who find social membership with a group outside the academic system may typically persist in their studies because they are interacting with the academic or social system of the university, but this is not always the case. For some students extreme social interaction could lead to them leaving their education if the group they associate with is not inclined towards academic achievement (Tinto, 1975). Similarly, students who are unsuccessfully integrated into their institution's social and academic life – from the students' point of view – tend to be less willing to continue onwards with their degree and thus have a higher risk of leaving the university (Terenzini & Pascarella, 1980; Tinto, 1975).

Networks and Student Retention

Like complex systems, social networks have been present, but in the background, in the development of theoretical models used to understand student retention, especially in the work of Tinto (1975, 1987, 1997). It has been recognized that the field of student retention needs to employ "network analysis and/or social mapping of student interaction... [to]...better illuminate the complexity of student involvement" (Tinto, 1997, p.619). Thus, it has been known for some time that the structures of social networks such as student satisfaction, academic performance, institutional commitment and study intentions are connected to student retention (for example, see Rizzuto, LeDoux, & Hatala, 2009; Sacredote, 2001; Thomas, 2000). Furthermore, it has been recognized that students' social networks can be a source of both support and stress for the students (Maundeni, 2001). However, complexity thinking and social network analysis tools have not been explicitly employed to explore the structure and dynamics of students' social and academic networks and how they are related to factors that influence student retention.

Conceptual Framework

In this paper, complexity thinking and social network theory are used to interpret physics and engineering students' social and academic networks. The structure and dynamics of complex systems are drawn upon, as well as social network theory concepts and measurements.

Complexity Thinking

Complexity thinking is anchored in complexity theory and aims to describe and understand complex systems and their capacity to show order, patterns, and structure (Davis & Sumara, 2006). Especially important is how these orders, patterns and structures seemingly emerge spontaneously from interactions between the systems' components. Complexity thinking is now used as a research framing across many disciplines (Mitchell, 2009), generating a theory that thus essentially "transcends disciplines" (Waldrop, 1992). Complexity theory is not characterized by a particular method but by a methodological perspective that employs a range of methods to study complex phenomena, and where the evolution of a complex system is understood to be largely unpredictable and uncontrollable.

Complex systems have been described as learning systems (Capra, 2001) because they are adaptive and self-organizing. Learning in this sense is understood as "ongoing, recursively elaborative adaptations through which systems maintain their coherences within dynamic circumstances" (Davis, 2004, p. 151). As a theoretical perspective in education complexity thinking uses characteristics of complex systems and conditions of emergence to both understand and prompt learning.

One can conceptualize the essential aspects of the structure, dynamics, and predictability of complex systems through metaphors (for example, see Gilstrap, 2005), computer simulations (for example, see Brown & Eisenhardt,

1997) and systems of modelling (for example, see Mowat & Davis, 2010). From this perspective, the essential aspects of complex systems that give rise to complexity theory's ubiquitous emergence are that all complex systems share similar structure and dynamics. Although the behaviour of complex systems such as society, organisms, or the internet can only be conceptually discussed as somewhere in-between complete order and complete disorder, any attempt to measure or distinguish one system as 'more' complex than another often breaks down (Mitchell, 2009). If a system is to be identified as being a complex system what needs to be investigated is the presence of the structures and dynamics that constitute complex systems, not the complexity itself (Davis & Sumara, 2006). For more details on the historical development of complexity theory, see Waldrop (1992), and for an overview of current applications of complexity theory in a wide array of fields, see Mitchell (2009).

The Structure and Dynamics of Complex Systems

Complex systems have been found to have a decentralized network structure where the connectedness of nodes is characterized by a power law distribution. This means that there are very few components or nodes that are much more connected than others – i.e. A small subset are more 'important' than others. This kind of structure can be contrasted to two other types of networks: (1) centralized networks with one central node where every other node is only connected to that central node; and, (2) distributed networks where all nodes have the same connectivity in the network. Information is shared efficiently in centralized networks but they are vulnerable to breakdown due to the dependency on the central node. On the other hand, distributed networks are robust to breakdowns but inefficient in sharing information. In the case of decentralized networks, when an 'important' component is removed or breaks down, then the whole system will suffer considerable damage, however the system will remain stable with the removal of any of the many less important or connected nodes. In this study, the “complex nature” of students’ social and academic nature will be inferred from the distribution of the connectivity of the nodes (students).

Due to their decentralized, scale-free structure, all complex systems are made up of components, which are themselves complex systems. Thus complex systems are described as nested. Nested systems are self-similar in that they share the same powerlaw distribution of the connectedness of nodes. Each level of complex organization exhibits similar structures and dynamics but operates within different time-scales and in different units of analysis. For example, mathematics learning-for-teaching has been modelled as several nested complex systems: subjective understanding, classroom collectivity, curriculum structure, and mathematical objects (Davis & Simmt, 2006). In using a complexity thinking perspective, we will consider individual students to be nested within social and academic cliques, which are nested within the larger social and academic networks. This allows us to examine three levels of analysis and to consider both network wide and clique specific structures and dynamics, while also allowing us to take individual characteristics into account.

One key aspect of the dynamics complex systems is that they are recursively adaptive to their own internal and external interactions, in this case adaptations occur in response to the students’ relationships with other students and teachers within the university and other networks outside the university. Through recursive adaptations, complex systems self organize; properties, behaviour and structure all emerge without an external system or an internal “leader system” that control the complex system (Davis & Sumara, 2006).

Social Network Theory

Complex systems are networked constellations of components, which in our example are the students’ social and academic networked interactions. Analysis of the structure and dynamics of the social and academic networks are possible through social network theory. The emphasis in social network theory is ‘structural relations’ (Knocke & Yang, 2008) i.e. it offers a way to explore the relations between the different structures in social networks. From such a framing the essential components of a network are the nodes (vertices) and the links (connections, edges) between nodes. In other words, social network theory is a powerful analytic tool to explore, come to understand, and characterize structure connectivity through network measurements within social and academic networks.

Our study visualizes and studies social and academic networks of students within engineering and physics courses. The nodes in the networks represent individual students within the network, and the edges represent type of relationships between students. Networks are characterized by quantifying connections between nodes. The nodes in a *directed network* have a *total degree* made up of the sum of *out-degree* (number of outgoing edges) and *in-degree* (number of in-coming edges) measurements. A way through a sequence of nodes that begins with the starting node and follows out going edges to other nodes through the network and ends at the end node is denoted as a *path* between nodes in social network theory. When every node in the network is reachable (i.e., there exists a path between every node) the network is said to be *connected*. If there are many paths between two nodes, the distance and number of edges in the different paths, are used to find the shortest path between nodes (Freeman, 1978).

Network Measurements in Relation to the Study

The networks were formed as *directed networks* using the responses from the network survey (described later in the methods section). The survey asked students to write down whom they interacted with and their responses were used to create a model of their social, academic and combined (social and academic) networks. In the analysis of the combined, academic and social networks as a whole, we analyzed distribution in degree nodes of the different networks (different groups and type) to investigate if the different networks show *self-similarity*. This gives an indication of the extent to which the different networks share structures and dynamics.

Using the average path length, it is possible to measure how far apart two nodes in general are in the network and to see how large or small the networks tend to be. We used a measurement of *modularity* (Newman & Girvan, 2004) to identify *cliques* (groups of students) within the networks and to compare the *cliques* in the social, academic and combined networks to see how stable a clique's structure is. We use *clustering coefficients* (Newman, 2003), both general and clique-specific, to measure how grouped the network tends to be and to see how tightly grouped the students are in their cliques.

To analyze individual roles within each network, we used *eigenvector centrality* (Bonacich, 1972) to identify important nodes, that is, the tendency for one person to be connected to other highly connected persons in the network. Furthermore, *closeness centrality* (c.f. Freeman, 1978) was used to identify students who are 'close' to other students within the network, i.e.

students are ranked according to the shortest possible path length to all other students.

Method

Network Survey and Retention Questionnaire

A network survey, grounded in the above described framing, was developed and tested. A final version was given to three physics and engineering classes at a Swedish university at the end of spring term 2010. Following Morrison (2002) the students were asked to write down the names of the people in the class that they interacted with and at the same time to characterize the nature of their interactions on a scale from *only social* (1) to *only academic* (5) with *both social and academic* being (3).

To draw connections between their social and academic interactions and programme retention students completed a questionnaire that asked a series of eight Likert answer questions regarding their attitudes towards their programme and subject of study (Questions can be found in Appendix I). The items are a subset of the variables which account for most of the variance in Cabrera et al.'s (1992) survey of undergraduate student retention. One question was added to our version of the questionnaire, (Q7: I have developed a good relationship with my teachers in the courses I have studied) in order to have a question that focused on students' interaction with teachers (something that has been found to be of critical concern to student retention (Spady, 1971; Terenzini & Pascarella, 1980; Tinto, 1975, 1987, 1992)).

Two of the classes where the questionnaire was handed out were in the first year of the physics and engineering program: a Mechanics II class (Group One) and a Computing Science class (Group Two). One year three class in an engineering program was also surveyed; Solid Mechanics class

(Group Three). The total population of Group One consisted of 154 students; 68 of these answered the questionnaire and 54 more were mentioned in the responses. In Group Two, the total population consisted of 113 students; 66 of these answered the questionnaire and 41 more were mentioned in the responses. Four more students, outside the surveyed population, were also mentioned. The total surveyed population of Group Three was 43 students; 23 of these students answered the questionnaire and three more were present in the responses.

Network Visualizations and Measurements

From the lists of names and classifications provided by the students in the network survey, two versions of three separate networks were created using Gephi 0.7 beta (www.gephi.org) for each surveyed group; a combined (social and academic) network, a social network and an academic network for each of the survey groups. The social network contained students' social interactions that corresponded with students' social bonds as noted by the students in the network survey. A social bond was interpreted to exist when students characterized their relationship as "only social" or "both social and academic" on the network survey. The academic network corresponded to students' academic interactions characterized by students on the survey with responses of "both social and academic" or "only academic". The combined network contained all student interactions, both social and academic, that corresponded with the students social and academic bonds as noted by the students in the network survey.

One version of each network was constructed using all students present in the network survey (i.e., students who participated in the survey and students who didn't participate but who were named by participating students), and one containing only the students who answered the survey. Using a complexity theory perspective and network measurements described above, networks were analyzed for differences between groups (types of physics and engineering courses), differences between years (year one compared to year three) and differences within groups (differences between each type of network: social, academic and combined).

Results

Visualizations

Using Gephi 0.7 beta, visualizations were generated for all students mentioned in the network survey for Groups One, Two and Three (Figures 1, 2, and 3) in order to make qualitative observations and interpretations. Visual representations of the combined, social and academic networks for each group are interpreted as sharing similar structural characteristics. Each group's networks are made up of clusters of networks that we will define as cliques using modularity and clustering coefficients. Furthermore, for each group, the academic network is more likely to display a group of students that are disconnected (or more disentangled) from the larger network. For example for Group One (Figure 1) the academic network has one large cluster and two small ones which are not connected to the larger network and Groups Two and Three (Figures 2 and 3) each have one cluster that is disconnected. Most of the students seem connected in the combined network for each group.

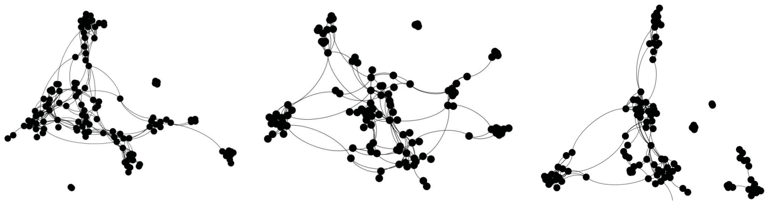

Figure 1: Network visualizations for Group One (all students N=154). From left to right: The combined, social, and academic networks.

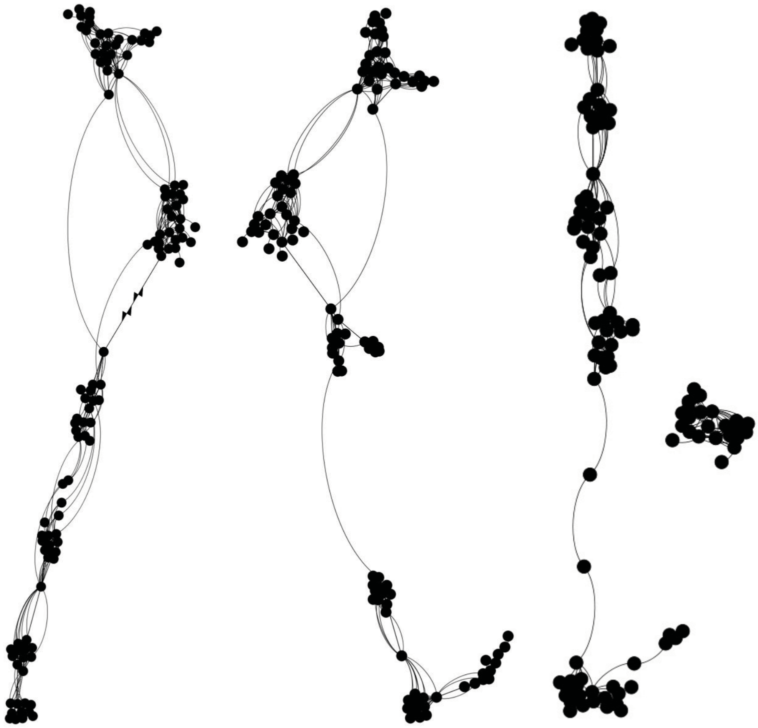

Figure 2: Network visualizations for Group Two (all students N=113). From left to right: The Combined, social, and academic networks.

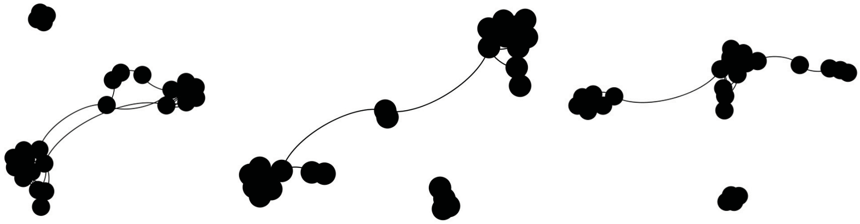

Figure 3: Network visualizations for Group Three (all students N=43). From left to right: The combined, social, and academic networks.

Degree Distributions

An analysis of the networks' degree distributions (number of nodes characterized by their in degree) was carried out to explore which networks share similarities within the same group, across groups, and across years. A calculation of the degree distribution was carried out for all types of networks and for each of the two versions (all students and surveyed students). To analyze the degree distribution of the networks, a logarithmic $p(k_{in})$ vs. k_{in} plot was constructed where $p(k_{in})$ is the probability to find such an in degree (k_{in}) in the network. A best fit regression analysis was conducted to evaluate which networks most closely resemble a complex system since complex systems have a degree distribution that can be described by a power law function.

The combined, social, and academic networks of all students in Group One strongly resemble complex systems, that is, they have a power law degree distribution with a mean R^2 of 0.83 and the mean R^2 for the version containing only surveyed students was smaller, 0.73. The student networks of Group Two, share some structures of complex systems. For all three networks, with all students present, the mean R^2 of the power law distribution fit was 0.57. In the versions of the combined, social, and academic networks with only the students taking the survey present, only the academic network's degree distribution could be described as a power law distribution (R^2 = 0.48). Group Three, showed only a slight resemblance to a degree distribution with a weak $p(k_{in})$ maximum around average degree of the nodes in the network, that suggests that it has a structure that is similar to a random decentralized system. No significant regression of degree distribution could be carried out to show self-similarity (mean R^2 = 0.04).

The difference in power law degree distribution between Groups One and Two, show that the students in the combined, social and academic network of Group One had more low degree nodes than in Group Two, but that they both exhibit a degree distribution that can be characterized by a power law. Groups One and Two are both first year classes and there is evidence that the social, academic, and combined networks that students form within their engineering and science classes during the first year of their program are more similar in structure to each other than to the year three group and that they share more similarities with complex systems (i.e., the degree distribution has a power law distribution and points to decentralized structure).

Degree distribution analysis results indicate that both versions of the student networks (one with only surveyed population and one which includes all students who were named in the surveys) produced similar results. In the remainder of this paper we will only present data from analysis of networks of all students present, however all calculations and analyses were carried out on both versions and it was ensured that no significant differences existed. Thus it is possible to conclude that it is valid to analyze the data using networks with all of the students present even though some were not a part of our surveyed population. These students are a part of the network around the surveyed students and we argue that using all students present in the network survey provides us with richer information of the structures of students' combined, social, and academic networks.

Average Path Length and Clustering Coefficients

A calculation of clustering coefficient (Newman, 2003) was carried out to compare how tightly grouped the networks were. We compared the clustering coefficient of the analyzed networks to the mean clustering coefficient of 1000 random network simulations with the same number of nodes and links. For all of the networks in all classes, the measured clustering coefficient was a factor of four to a factor of 15 larger than the corresponding random network (See Table 1). The analysis shows that for all three groups, the tendency of tightly connected groups is at its highest in the combined network of students, and at its lowest in the academic network. This is corroborated by qualitative observations of visualizations (Figures 1, 2, and 3).

To globally measure how "far away" students tend to be from one another in each network, a calculation of average path length was produced (see Table 1). In Group One and Group Three, students are most close to everyone else in the social network when compared with the other networks which is indicated by a lower average path length compared to academic and combined networks. Students in these groups tend to be more far apart in the combined network, or even unreachable as no paths exists between them in their academic network. This trend is different in Group 2, where the academic network has a shorter average path length than the social or combined network.This could be explained visually where the academic network is divided into two separate academic networks with no connections between them (Figure 2). Therefore, the students have no direct academic connection to roughly one third of the class and thus the calculation of the average path length is smaller because there are fewer long paths in the network.

Table 1: Clustering coefficient and average path length for all networks. “S+A” denotes the combined network. “S” denotes the social network and “A” denotes the academic network.

All Students	Simulation of Random network - mean clustering coefficient	Clustering Coefficient	Average path length
G1 S+A	0.027 ± 0.004	0.393	3.802
G1 S	0.027 ± 0.005	0.364	3.572
G1 A	0.026 ± 0.005	0.247	4.479
G2 S+A	0.050 ± 0.004	0.519	5.424
G2 S	0.041 ± 0.004	0.424	4.252
G2 A	0.034 ± 0.005	0.374	2.844
G3 S+A	0.174 ± 0.019	0.636	2.136
G3 S	0.147 ± 0.022	0.512	1.390
G3 A	0.124 ± 0.023	0.517	2.060

The clustering coefficients of each group and each type of network can be compared. The least clustered is Group One (G1) (year one Mechanics II class) and the most clustered is Group Three (G3) (year three solid mechanics). The least clustered network within each of the groups is the academic network. Thus, these students have the least intra- and interconnected cliques nested within their academic network. The most extreme example of this can be found in Group Two (G2) where the academic network became divided into two separate networks.

Cliques

Using *modularity* (Newman & Girvan, 2004) cliques (groups of students within a class or group) were identified in the combined, social, and academic networks. A stable clique was defined when at least 80% of the clique members were connected to each other in a sub-group which was present in the combined, social, and academic networks. Findings suggest that most cliques are inclined towards stability for each group. Analysis found 17 different groups in the different networks. Results show that 76% of all cliques are stable across the three networks, 18% are split in the social network but stable in the combined and academic network, and 6% are split in the academic network but are stable in the combined and social network. Analysis of clique membership and students' choice of programme were conducted using cross-tabulation in SPSS. An example visualization of Group One's clique members and their programmes of study is presented in Figure 4 and shows that programme is an important predictor of a students' membership in a clique. Similar trends were observed for Groups Two and Three.

Figure 4: The combined network of Group One with cliques and programmes represented. The small nodes represent individual students and the larger nodes represent the students' programme. Note: The shading on smaller nodes identifies the clique membership. The shading on larger nodes indicate that each node corresponds to a different *degree programme*.

Individual Characteristics

Network measurements of students' structural centrality (*closeness centrality and eigenvector centrality)* and node degree *(in, out* and *total degree),* from all three networks of each group containing all students who were present in the network survey were correlated with course grade and degree of course completion using Pearson's correlation. Students' course grade were within the range of fail (0), Pass (3), and towards higher grades of (4) or (5). Group One had 48 students who passed or had a higher grade, and 75 students did not complete the course, Group Two had 105 students who passed or had a higher grade, and six students who did not complete the course, and Group Three had 20 students passing or getting a higher grade, and three students who did not complete the course. The courses provide partial credits for completing separate pieces of the course. The degree of course completion ranged from zero to five, with incremental steps for each part of the course completed. Correlations were also carried out between network measurements of the combined, social, and academic networks and responses to the retention questionnaire. Only two items out of a total of eight in the questionnaire: Q6 - It has been easy for me to meet and make friends with other students at this university and Q8 - I will re-enroll at this programme next semester.

Closeness Centrality

In analyzing the results of the network measurements of closeness centrality (Table 2), we found that students who are "close" (have higher closeness centrality) to other students in the combined and academic network of Group One tended to have a higher grades for each of the three networks. However, the combined and academic networks of Group One also had significant correlations between closeness centrality and course completion. For Group Two, the second group of first year students, closeness to other students in the combined network was also tied to degree of course completion. Thus for Groups One and Two (first year students) there appears to be a trend between how close students are to each other and academic measures such as the likelihood of achieving good grades and course completion rates. These tendencies are stronger in combined and academic networks than social networks.

Students in Group Two, who were close to other students in their social and combined network had a tendency towards experiencing that they had an easy time meeting new friends while students in Group One's academic network with high closeness centrality experienced a hard time meeting new friends and had a significant negative correlation. This there was no clear trend between closeness centrality and ease of making new friends.

Table 2: Pearson correlation of closeness centrality and course grade, degree of course completion, and question 6 and question 8 on the questionnaire. (*: p<.05, **: p<0.01).

Closeness centrality	Course grade	Degree of course completion	Easy finding new friends	Intent to persist
Combined network of Group One	.182*	.190*	.057	.071
Combined network of Group Two	.150	.192*	.253*	-.078
Combined network of Group Three	.255	.226	-.026	-.469*
Social network of Group One	.193*	.180	-.015	.216
Social network of Group Two	.164	.147	.261**	.123
Social Network of Group Three	.101	-.050	.138	-.118
Academic network of Group One	.270**	.201*	-.249*	-.015
Academic network of Group Two	.106	.174	-.048	-.281*
Academic network of Group Three	.010	.106	.261	-.559**

Students in Group Three who were close to other students in their combined and academic network tended to answer that they were not going to re-enroll (or study abroad) the next semester. Students in Group Two who were close to every other possible student also had a negative trend in their answer on re-enrollment for next semester. Thus there may be a negative trend between measures of closeness and intent to persist in the programme in both first and third year students.

Eigenvector Centrality

The individual characteristics of students who were interacting with students who also were interacting with many other students, indicated by their *eigenvector centrality*, were explored (Table 3). We find that Group One has a strong correlation between their *eigenvector centrality* and the course grade and degree of course completion for all three networks. We find a connection between the students with a higher *eigenvector centrality* and students in both the combined and social networks of Group Two and Group Three that tend to experience that they have had an easy time meeting new friends. A negative trend exists between Group Three students' answers on intent to persist in their studies (re-enroll in the next semester) and the eigenvector centrality of each of the three networks. Therefore there appears to be differences among groups on measures of eigenvector centrality.

Table 3: Pearson correlation of eigenvector centrality, and course grade, degree of course completion, and question 6 and question 8 on the questionnaire. (*: p<.05, **: p<0.01)

Eigenvector Centrality	Course grade	Degree of course completion	Easy finding new friends	Intent to persist
Combined network of Group One	.274**	.329**	.086	.172
Combined network of Group Two	.009	.141	.412**	-.029
Combined network of Group Three	.206	.187	.567**	-.539**
Social network of Group One	.286**	.271**	-.042	.069
Social network of Group Two	-.050	.110	.407**	.036
Social Network of Group Three	.147	.084	.696**	-.564**
Academic network of Group One	.223*	.257**	.171	.183
Academic network of Group Two	.041	.101	.175	.103
Academic network of Group Three	.139	.175	.396	-.524**

In Degree

Analyzing mean students' in degree (number of students who indicated in the survey that they studied with one particular student) of each network, we find no significant correlation to academic performance in any of the groups' social networks (Table 4). In Group One and in Group Two, the first year students, we find that the in degree of the students' academic network has a significant correlation to course grade.

Group One is the only group where we find that the in degree of student has a significant correlation to the degree of course completion and this occurs for the combined and academic network.

For the students' combined and social networks in Group Two and Three, we find significant correlations between in degree and their answer of their experiences in meeting new friends. Furthermore, we find a negative trend for Group Three in their intent to persist in their studies (re-enrollment in the next semester) and the in degree of the combined and social network.

Table 4: Pearson correlation of in degree, and course grade, degree of course completion, and Question 6 and Question 8 on the questionnaire. (*: p < .05, **; p < 0.01)

In Degree	Course grade	Degree of course completion	Easy finding new friends	Intent to persist
Combined network of Group One	.194*	.251**	.144	.180
Combined network of Group Two	.124	.174	.136**	-.123
Combined network of Group Three	.255	.177	.546**	-.482*
Social network of Group One	.079	.129	.149	.209
Social network of Group Two	.007	.135	.430**	-.110
Social Network of Group Three	.179	.061	.677**	-.484*
Academic network of Group One	.236*	.250**	.109	.065
Academic network of Group Two	.196*	.111	.171	.026
Academic network of Group Three	.242	.198	.397	-.309

Does it then mean that if one student has a particular important position or is a part of an important structure in one type of network, it holds the same importance in the other types of networks? This study sought to look for differences between social and academic networks, thus network measures (in degree, closeness centrality and eigenvector centrality) for the social and academic networks for each group were compared to each other. Comparing network measurements between the social and academic network (Table 5), we find positive correlations in all groups of their *in degree* (number of students that students identified as friends) and *eigenvector centrality* (the connectedness of the students they are connected to). We find that being students being close to every other students in the social network, does not automatically lead towards a tendency of being close to every other student in the academic network.

Table 5: Pearson correlation between network measurements of the social and academic networks of each group (*: p < .05, **; p < 0.01).

Correlations between network measurements of the social and academic network		Group One	Group Two	Group Three
In Degree	Pearson Correlation	.604**	.499**	.583**
Closeness centrality	Pearson Correlation	.204	-.381**	.212
Eigenvector centrality	Pearson Correlation	.333**	.416**	.739**

Discussion

Comparing the social and academic networks of first and third year physics and engineering students, and exploring the structures of these networks, it can be concluded that there are both similarities and differences. The structure of the social, academic and combined networks were described by examining the degree distribution of their nodes, the clustering coefficients, and path length. Using the degree distribution it was illustrated that the first year groups, Group One and Group Two, had strong similarities with a complex system as their degree distributions could be modeled by a power law distribution. Group One, with the group with the closest fit to a power law distribution, also had the highest correlations for students' individual characteristics such as academic measures and student retention factors. Clustering coefficients were measured for each type of network and for each group and similar trends were observed. The networks were much more clustered than a random network would be and social networks are more tightly knit than academic networks. Average path length measurements illustrated differences between social and academic networks, where social networks tended to have shorter path lengths than academic networks. Thus students' social networks are structured such that most students are close to each other, whereas academic networks are more distinct – students work closely with some, but not all of their fellow students. Visualizations of student networks illustrate a similar trend, where the academic networks for each group were more likely to have a completely separate group of students who work together.

Tinto (1997) posited that the social and academic systems, and in our case the emerging structured networks of students' social and academic interactions, are nested within each other. Complexity thinking defines nested systems as complex systems that exist within a greater complex systems and which have similar structures and analysis but operating on different scales. Our analysis of these networks supports this and suggests that the social and academic networks are nested in each other (for example cliques exhibit stability across social and academic systems) and create a larger network of interaction for the students. It is important to note is that this research suggests that both the social, and academic network structures and dynamics will affect the larger system's structure and dynamics. This study's findings about the structure of student social and academic networks can help researchers and educators understand how to exploit the structure of student networks to support students in their studies. Findings suggest that to strengthen their social and academic networks they should be encouraged to socialize and work with students from other programmes, particularly when doing academic work. Complexity thinking suggests that this would strengthen students' academic networks to the close knit level that students' social networks are clustered.

Grouping of cliques of students in the combined, social, and academic network show that the members of a clique tend to study within the same programme. Most cliques are stable in all three networks, however the cliques which are unstable are most likely to be found within the social network. Therefore students' programmes play an important role in the social and academic networks that they form. It is recommended that universities provide opportunities for students to interact with members of their programme and to form ways to develop an identity specific to their programme.

Individual characteristics of students within social and academic networks were examined with closeness centrality, eigenvector centrality, in degree, grades, degree of course completion and responses to eight items on a retention questionnaire. Similarities across types of networks were found. Within the network measurements it was found that closeness centrality (students interacting with and having low path lengths to most of the other students in the classroom) holds an explanatory value of degree of course completion grade in two networks (academic and combined) for Group One and Group Two (first year students). For Group One, high closeness also correlated with high grades in the academic and combined networks. The link between a combined network and grade performance has previously been found in work done by Thomas (2000) and Sacredote (2001). When social and academic network measurements were correlated it was found that in degree and eigenvector centrality were closely correlated for all three groups, but that closeness centrality was not necessarily similar for social and academic networks.

Dissimilarities of the social and academic network were found within the analysis, which suggests that there could be different constructs within the 'social' and 'academic' systems (Tinto, 1975, 1987, 1997) governing the interactions within the two different networks. It was found that the network measurements of the social system had less in common with academic achievement than the network measurements academic network. This is especially visible in the analysis of students' in degree, where significant correlations between academic performance, such as course grade and degree of course completion, were found in the academic and combined networks but not the social network for Group One. While the measurements of the social network had more in common with items in the retention questionnaire which were tied to the social side of attending an university such as how easy it was to find friends. Furthermore, we find empirical evidence that suggests that students that are close to other students in the social or the academic network does not automatically lead them to be close in the other network. We even found evidence that in one case (Group Two) it has the opposite effect, which harmonizes well with previous research that suggests that students who are have an extreme proportion of social interaction can be less integrated into the academic system (Tinto, 1975) and may be less likely to complete their studies. Group Three had negative trends between several network measurements and Q8 on the retention questionnaire about students' intent to persist. Furthermore, this finding also suggests that there is a possibility that students who have an extreme proportion of academic interaction can become less integrated into the social part of the university.

Differences between networks within different courses and years were found. The students in the surveyed courses had differences in clustering, which means that the strongest ties between the members of a clique were found in Group Three (year three students), and the weakest ties between members of a clique was found in Group One. Furthermore, findings suggest that types of centrality, not only closeness centrality, play different roles in the surveyed networks. In Group One, eigenvector centrality (students who interact with students who have interactions with a large proportion of the class) of the combined and the academic network had a larger explanatory power of course grade and course completion. In Group Two, the closeness centrality of the social network was connected to the degree of course completion. Therefore Group One likely has a few influential students who maintain the connectedness of the larger group, where as Group Two may have more students who are moderately connected. Thus network measurements provide insight into the unique characteristics of each group of students.

We can conclude that there is evidence for the presence of a ‘social’ and an ‘academic’ system (Tinto, 1947, 1987, 1997) which can play a role in governing student to student interactions. The analysis of this study provides an example of a method that could be used to better understand the structure and dynamics of these networks and illustrates it makes sense to separate the interaction network of courses into two, separate networks.

This study is limited in the number of students who were surveyed and the results cannot be used to make generalizations about students’ social and academic networks. It aims to illustrate that complexity thinking interpretations and social network tools can be used to look more deeply into the structure of student social and academic networks. This study provides evidence of the types of structures that social and academic networks may have and suggests some possible measures that could be used to examine them. The next steps in this research is to collect data from a much larger sample and employ these tools to try to characterize student social and academic networks in more detail.

Educationally Significant Findings

This paper has used complexity thinking and network analysis tools to visualize and characterize a 'learning classroom' as a complex system of student interactions. Differences between social and academic networks were observed. Students have more connections to a wider variety of students in their social network but this does not typically correlate with high grades and course completion. Thus educators need to start to think about how students with strong social networks can also be supported academically, i.e. how can students' social and academic networks become more integrated during their studies. In the population of students surveyed three network measures of the students' role in the academic network were found to be connected with a tendency towards better grade performance and degree of course completion: short relationship ties to every other student and connections with students with many connections. This can provide a basis for teachers wanting to use teaching methods that are designed to improve the quantity and hopefully the quality, of student interactions within a course.

In conclusion this study has offered some preliminary findings that can help researchers and educators interested in student retention to visualize and examine the structure and components of students' social and academic systems in physics and engineering undergraduate programs. Social network analysis tools were used to characterize the social and academic systems as complex and nested, with some similarities and stable structures but also with differences such as likelihood to correlate to academic measures of success and closeness centrality. A larger sample is needed to make stronger claims about what social and academic system structure looks like, but the results of this study provide an example of the kinds of findings such an analysis could generate.

Acknowledgements

The authors would like to thank the participants for volunteering to take part in this study. Correspondence to: Jonas Forsman, jonas.forsman@fysik.uu.se.

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Appendix I – Questionnaire

Q1. I am satisfied with my course curriculum

Q2. My close friends encourage me to continue my studies at this university

Q3. I feel I belong at this university

Q4. My degree from this university will help secure future employment

Q5. I am satisfied with my experience of Higher Education

Q6. It has been easy for me to meet and make friends with other students at this university

Q7. I have developed a good relationship with my teachers at the courses I have studied

Q8. I will re-enroll at this programme next semester

Paper III

- A pilot study of the structure and evolution of students' supportive networks.

Based on a poster Presented at the NU2010 conference:

Forsman, J., and Andersson, S. (2010), Studenters stödjande nätverk. Poster presented at the NU2010 Dialog för lärande Conference, Stockholm, Sweden, October 13 – 15.

A pilot study of the structure and evolution of students' supportive networks.

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Presentation form: open squares in NU2010

Theme 4 Student Dialogue

Background

Student retention research has found that a successful integration into various social and academic systems in higher education plays a role in students' decisions regarding continuation of their studies (Tinto, 1975, 1987, 1992, 1997). Integration into these systems is essentially grounded in the interaction between students (Tinto, 1987), between students and faculty (Pascarella & Terenzini, 2008; Kuh & Hu, 2001), and between students and other university staff (Kuh & Hu, 2001).

More recently, social and academic integrations were analyzed according to how well-connected students became in social and academic networks. These networks are built in the interaction between students, teachers and university personnel (Thomas, 2000). From this network-perspective, students' networks of people or functions available in universities or colleges, comes into focus in student retention research.

We present results from a pilot study to lay a theoretical foundation for the modelling of the evolution of student support networks in Higher Education. We chose to analyze the social and academic integration from a network perspective (Knocke & Yang, 2008), in which students with a larger and efficiently connected support network is an indication of the social and academic integration. The focus of this study is on how various student related support functions may have the ability to allow new connections to other support functions.

Method

Thirteen programs of students in the Master of Science in Engineering Physics at a Swedish university were asked to draw a network map of the things that they perceive to be supportive of them as a student. To investigate the possible evolution of support network function, students from year one to year five participated in the survey.

The various support functions in students' networks catalogued along the academic / social function (Tinto, 1997) and larger groups of "support functions". This generated a combined network map describing the possible sets and connections of all support functions for students in the population studied.

We used combined network map and the statistical package Statnet (Hand Cock et al., 2003) to determine the different functions' frequency to be between other support functions. By using the network measure *betweenness centrality* (Bernhardsson, 2009) support functions that have a higher frequency of being between other support functions and thus have the ability to open up more connections were identified.

Results

First we examined each student's network, which showed that the larger networks with more connections between the support functions were found more often among the students who studied at the end of their programme of study. The classification and analysis of students' different network gave a combined network.

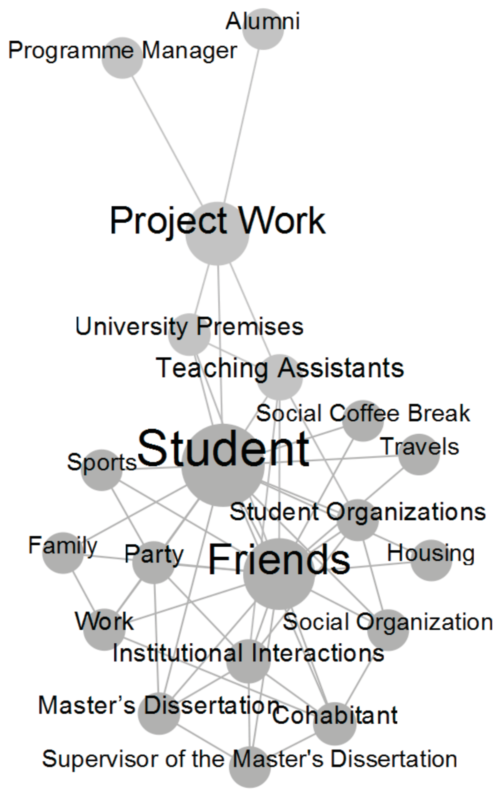

Figure 1: Aggregated network of students' supportive network.

From analysis and compilation of the student network, it was found that the support functions are different between the different students. From how common support functions are in the various networks that the students answered, classification of support services into two groups was possible: (1) *The frequent*, appearing in eight (out of thirteen) or more student networks, are *Friends*, *Family and Partner*, *Social Organizations*, *Academic communities*, *Courses and Master's Dissertation*, *Social Activities* and *Student Organizations*. (2) *The infrequent*, appearing in five (out of thirteen) or fewer student networks, were *Work*, *Housing*, *Institutional Interactions*, *Project Work*, *Alumni*, *University Premises*, *Program Manager*, *Teacher Assistant*, and *Supervisor of the Master's Dissertation*. *The infrequent* support functions were mainly found among those students who were near the end of their degree programme.

From network measurement of *betweenness centrality*, the networked support functions significance for the evolution of the network can be interpreted. The analysis showed that *Friends*, *Project Work*, *Teaching Assistants*, the *Institutional Interactions*, *Family and Partner*, *Courses and Master's Dissertation*, and *Student Organizations* were the features that were most able to open up for interaction with new support functions for students in this study.

From *the frequent* support function group, identification based on betweenness centrality were conducted and *Friends*, *Family and Partner*, and *Student Organizations* was interpreted to have the greatest opportunity to open up pathways to know about and have a link with more support functions. From *the infrequent* group of support functions, identification of *Work*, *Project Work*, *Institutional Interaction*, and *Teaching Assistants* was interpreted as having opportunity to new paths to more support functions for students.

Discussion

Our study shows that the most important way to access different types of support functions is through social and academic network that has students at the university. Student networks within and outside the university can fill a dual role: both in itself are supportive, and to provide opportunities to expand the student's network of other support functions.

Based on network analysis and by using previous research by the students' courses in higher education, we argue that the expansion of the student network at the beginning of the training takes place primarily through friends, family and girlfriend and various student organizations. Later in the program work, project work, social and academic life at the department, and teaching assistants grant a greater role for the evolution of the support network.

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