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# THRESHOLD CONCEPTS APPROACH TO CURRICULUM DEVELOPMENT: A MISSING PIECE IN CHEMISTRY STUDENTS' RETENTION PUZZLE?

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**Abstract:** Retention of students is an area of high interest for educational researchers and university policy makers across the globe. The interplay between institutional factors and students' personal characteristics and circumstances are playing a key role in students' retention. It has been revealed that a student-centered curriculum and students' engagement are amongst the pivotal factors in students' retention. A threshold concepts-centered curriculum has the potential to facilitate acquirement of core concepts in a field and to support deep learning. Furthermore, the identification of threshold concepts with students presume enhanced students' engagement. Many concepts in Chemistry have been defined as threshold concepts. Herein are presented the grounds for proposing that threshold concepts-centered curriculum may play a pivotal role in students' retention, alongside with other institutional and personal factors.

**Keywords:** threshold concepts, curriculum development, dropout, Chemistry students‘ retention

## 1. Perspective Presentation

Retention of students in their studies plays a central role in attainment of university quality assurance and is an area of interest and concern across the globe. Furthermore, student drop out is an issue affecting students' lives and careers, as well as universities' reputation and finances. The interplay between students' personal characteristics and circumstances and institutional conditions are considered to be accountable for students' retention or drop out (Tinto, 1975). Good teaching leading to high-quality learning as well as a student-responsive curriculum are two key strategies to be adopted by universities for increasing students' success and retention (Crosling *et al.*, 2009). Threshold concepts were first introduced by Meyer and Land (2003) and are considered to be pivotal in the acquirement of core concepts in a field. Threshold concepts foster deep learning and the formation of students' thinking specific for a discipline. A curricular reform for the introduction of a curriculum focused on threshold concepts was previously proposed (Land *et al.*, 2005). Empirical data has proven that the dropout rate of Chemistry students is higher than the dropout rate of social science students (for an example of such comparison, see Heublein, 2014). Middlecamp (2015) states that there are four factors important for Chemistry students' success (especially for disadvantaged students): the faculty, the students, the curriculum, and the campus climate. The harmony or disharmony between these four factors may result in students' success and retention or drop out. Herein is presented a perspective for inclusion of curriculum based on threshold concepts in Chemistry students' retention puzzle.

## 2. Drop Out : theoretical models and prevention strategies

A number of several drop out models were proposed and they were reviewed in detail elsewhere (Demetriou, 2011). In the models from 1970s and 1980s, the social integration of students with peers and academics was considered to be a key factor in students' retention or drop-out. Starting with 1990, the diversity of students and their support needs were taken in acount in drop out models. Tinto's model is the most popular model and along the time Tinto revised it, to include new findings and to adapt it to students' situations. According to Tinto's (1975) initial student integration model the

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dropouts are the students who failed to adapt academically and socially to the university's system. In this model the interaction between the individual and the institution is regarded as key; the individual may modify continuously the goals and his/her institutional commitment, resulting in persistence or drop out. The decision to stop studies at university level is not a decision taken spontaneously and can be taken by the student (drop out) or by the institution (dismissal). Later on Tinto (2004) emphasized the importance of university policies supporting the creation of opportunities for easy interaction of students with academic staff, administrative people and personnel from student services department. Furthermore, it is presumed that the expectation for students to succeed presupposes an improvement in students' support policies, with consequences for students' retention (Tinto, 2006). A model for moving from theory to practice proposed by Tinto included: institutional actions for student success, institutional action and leadership, expectational climate, support (financial aid, advising, academic support, social support), feedback, chaperoning students' involvement (pedagogies of engagement, learning communities). Faculty members could take action in improvement of pedagogies, curricula and assessment (Tinto, 2006). Nevertheless, there are a number of empirical studies based on Tinto's model (Sarker *et al.*, 2014, pp. 58-71) and it was revealed that variables from Tinto's model can explain only 0.35 of variance.

In a report regarding studies on drop out amongst students from under-represented groups in Europe are presented six key factors which contribute to drop out: socio-cultural factors, structural factors, policy factors, institutional factors, personal factors, learning factors. These factors are inter-related and it is generally a mixture of factors contributing to drop out. In the same report are presented a list of 14 strategies which universities could adopt to diminish dropout rates (Quinn, 2013, pp. 59):

'Type 1: Preparing students for higher education

Type 2: Supporting transition into higher education

Type 3: Tracking student engagement with higher education

Type 4: Creating a more relevant and supportive curriculum

Type 5: Creating more responsive pedagogies

Type 6: Fostering positive approaches to learning

Type 7: Improving formative assessment

Type 8: Improving student study skills

Type 9: Offering financial support to students

Type 10: Offering counselling and personal support to students

Type 11: Fostering student personal networks

Type 12: Targeting support for specific disciplines

Type 13: Targeting support at specific groups of students

Type 14: Demonstrating the future utility of higher education'

Amongst them is depicted a strategy ('type 4') regarding the provision of a curriculum which is adjusted to students' needs and is supportive of students' needs. Furthermore, in a report of Vardi (2015) regarding the strategies for retaining 'non-traditional' students, the following factors are mentioned as having an impact on retention, achievement and progress: curriculum and its delivery by the teaching staff, the students' characteristics and the class culture. Furthermore, adopting a student-centered approach to learning rather than a teacher-centered approach would have an impact on students' engagement (Bryson *et al.*, 2007). A method to promote student engagement is to create a student-responsive curriculum (Crosling *et al.*, 2008). Crosling *et al.* (2008) state that authentic curriculum and student centered active learning are pivotal factors for students' retention and success.

## 3. Learning with Threshold Concepts-centered Curriculum

Threshold concepts were introduced in 2003 by Meyer and Land and are considered to be the underlying rules, patterns which govern the understanding specific to a discipline and which connect the discipline together. The threshold concepts are a set of principles specific for a discipline (O'Donnell, 2010). Threshold concepts are similar to a portal, conceptual gateway, opening up new ways of understanding. They can facilitate deep learning for students who comprehend them, but also could be the important factors leading to unsuccessful study outcome for the students who are not able to grasp them. The transition period between the moment in which students did not acquire a threshold concept and the moment of grasping the threshold concept is like an initiation moment, is a 'liminal space'. The moment of grasping of the threshold concept can be described as a 'Eureka!' moment, a cognitive shift, a shift in awareness, as well as an ontological and individual one. Therefore, the acquisition of threshold concepts may involve conceptual change. Once the threshold concepts specific to a field are grasped by students, they acquire the specific thinking to that field and they are able to view the world in the way specific to that field.

Characteristics of threshold concepts as described by Meyer & Land (2003):

- Transformative: determine a shift in perception
- Irreversible: it is not probable that once understood, would be forgotten or unlearned
- Integrative: revealing connections which were not understood previously
- Bounded: having 'terminal frontiers' at the border with other threshold concepts from other conceptual areas.
- Troublesome: firstly counter-intuitive or difficult to grasp

Perkins (1999) described four types of troublesome knowledge:

- *Inert* or abstract knowledge: has to be learned without context
- *Ritual* knowledge: is learned with no understanding
- *Conceptually difficult*: is counter-intuitive and may be misunderstood because of common knowledge.
- *Foreign or alien* knowledge: the perspective is new to the learner.

Meyer and Land (2003) added two additional types of troublesome knowledge:

- *Tacit* knowledge: is not clearly identified, taught, or learned.
- Knowledge with *troublesome language* uses new language or language that may be misunderstood because has other meaning in daily life.

It is considered that the characteristics 'troublesome' and 'transformative' are the key characteristics for a concept to be identified as a threshold concept. With regard to the methodology for the identification of threshold concepts, students, teachers and academics were engaged in the identification process (Barradell, 2013).

Cousin (2006) stated that a threshold concepts approach to curriculum design is a 'less is more' approach to curriculum design**.** Land *et al.* (2005) named threshold concepts *'jewels in the curriculum'*: they can be used to define potentially transformative points in students' learning experiences Åkerlind *et al.* (2011) propose a methodology for curriculum development including threshold concepts. The steps involved are: a) identification of threshold concepts, b) phenomenographic research to recognize students understanding / misunderstanding of threshold concepts, c) use of variation theory for design of curriculum around the topics identified as threshold concepts. The strategy for design of curriculum involving the use of variation theory would address the issue regarding students' misunderstanding of threshold concepts. The authors state that 'variation theory would give students opportunities to experience variation in aspects of disciplinary concepts that they currently take for granted' (Åkerlind *et al.*, 2011, pp. 7). This project was undertaken for Law and Physics students, at four universities in Australia. The practical shortcoming of this approach is the requisite of a multitude of resources for its completion. However, the authors considered that the project is 'transportable' to different disciplines and institutions. The drawback of such project would be that not all threshold concepts would be a threshold concept for each student. Therefore, studies should focus on the concepts which are threshold concepts for most of students. Furthermore, the identification of threshold concepts by students means that students are engaged in curriculum development (Male & MacNish & Baillie, 2012).

## 4. Threshold Concepts in Chemistry

For Chemistry, there are a number of threshold concepts identified in empirical studies (Moss *et al.*, 2007; Park *et al.*, 2009) or presented as possible threshold concepts in theoretical papers (Ngai & Talanquer, 2014; Talanquer, 2015).

Moss *et al.* (2007) provided lists of concepts which were identified by students, science teachers or academic staff to be threshold concepts. All participants identified that those topics which are involving the molecular level and so, are difficult to be visualized by students, are problematic, as well as anything which involves the behavior of electrons. Furthermore, the topics in Chemistry which involve equations or the utilization of statistics are also troublesome. Park *et al.* (2009) discussed the reasons why atomicity is a threshold concept for students. The legitimated model of atomicity is difficult to grasp, troublesome, and students have alternative mental models of atomicity. Therefore, this is a threshold concept. In a recent study Park (2015, pp. 311) reveals the identification of seven threshold concepts identified by high school teachers in Korea: 'mole, ideal gas law, periodic table, structure of an atom, electron configuration, orbital, chemical bond, and chemical equilibrium'. The results of Park's study provide evidence that teachers reflect on their knowledge when preparing to teach using threshold concepts. This has an impact on their pedagogical content knowledge development.

Ngai, Sevian & Talanquer (2014, pp. 2439) reviewed the research finding regarding students' misconceptions in chemistry and listed six crosscutting disciplinary concepts that could be pivotal in assisting the integration of knowledge in chemistry: 'chemical identity, structure-property relationships, chemical causality, chemical mechanism, chemical control, and benefits-costs-risks'. Talanquer (2015) provides examples of a few concepts which are potential threshold concepts: atomicity, chemical bonding, intermolecular forces and chemical equilibrium. The students employ implicit (*ie*, tacit, unconscious) schemas in their thinking and for students to be able to grasp the threshold concepts, a shift in their schemas must at first occur. The conceptual areas in which these shifts should occur are: properties of substances, processes, population in a system, the changing nature of chemical properties in function of their environment, the causality of change in a system (Talanquer, 2015).

Davey (2012) reports that Chemical Engineering students perceived as beneficial the tasks in which they were involved actively in the presentation and discussion of threshold concepts. Davey (2015) attempted to evaluate if teaching with threshold concepts could impact the students' self-perceived engagement. The conclusion was that a more in-depth study is necessary to draw such conclusions and the results of such study could be biased by the fact that not every threshold concept is a threshold concept for each student. Furthermore, Davey (2015) states that when it comes to students' success, the importance of the lecturer and of the course structure should not be diminished in front of the importance of students' engagement.

Duis (2011) made a study regarding students' misconceptions in organic chemistr**y**, by interviewing educators at tertiary level, in American Chemistry Society-accredited institutions. Results of Duis (2011, pp. 348) study revealed that amongst the difficult topics of organic chemistry, are 'reaction mechanisms, acid-base chemistry, synthesis, stereochemistry, resonance (electron delocalization), molecular orbital theory, spectroscopy, polarity, SN1, SN2, E1, E2 reactions, and curved-arrow formalism.

Some of the threshold concepts identified in the study of Moss (2007) by first year Chemistry students were SN1, SN2 reactions, inductive effects and anything which involves the behaviour of electrons. The fact that the topics which were identified as threshold concepts were also identified as the concepts in which students have misconceptions is one more reason to consider threshold concepts as an important factor to be considered in curriculum development for student-centred learning.

## 5. Dropout and curriculum reform: the case of chemistry students

Studies on dropout focused on finding the predictors for study success (for an example, see Freyer *et al.*, 2014). Similar to the results of studies testing empirically the theoretical dropout models, only a percent of variance can be explained. Universities adopted strategies for students' success and retention, specific for chemistry field. A list of approaches adopted by universities for students' success and retention is presented below:

- flipped classroom

Improved students' results were obtained in the flipped classroom compared with the control group (Ryan & Reid, 2015)

- peer led team learning

A 15% improvement in the pass rate of the class was observed in the class where peer led team learning was implemented, as compared with the lecture-only class (Lewis, 2011)

- cooperative learning with enhanced communication

Cooperative learning with enhanced communication has a positive effect on student learning and retention (Dougherty *et al.*, 1995).

- Problem solving-based class

Problem solving strategies provide to be fruitful and a curriculum based on problem-solving could be proposed for implementation (Obomanu *et al.*, 2010)

- One-to-one learning environment

It has been shown that one-to-one learning environment has a positive effect on the reduction of the number of unsuccessful students (Baez-Galib *et al.*, 2005).

- Introduction of a 'Introduction to Chemistry' course

In order to aid transition and success of students who studied minimal hours of Chemistry before entering university, special strategies must be provided by universities. It was proven that introduction of a 'Introduction to Chemistry' course and of small-group learning increases the pass rate of this type of students (Hall *et al.*, 2014).

Efforts for curriculum reform in chemistry proposed an increase in the amount of experimentation during lecture and of interactivity during lecture. For this purpose, it was suggested that the courses should be reformed, curricula should be organized around a small number of topics, and that the content of course and laboratory should be aligned (Hopkins *et al.*, 2013). In a transition and retention guide provided by British authors (Bramhall *et al.*, 2012) there are a few strategies proposed for curricular reform which could have a positive impact on retention. These activities are: project based active learning, interdisciplinary project and course, activity – led learning. Mbajiorgu & Reid (2006) discussed the factors which should be considered when developing a curriculum in chemistry, for either school or university level. The list provided by Mbajiorgu & Reid (2006, pp. 2) is a result of literature research and is based on the results and findings of empirical studies.

'The chemistry curriculum should:

1. Meet needs of all learners
2. Relate to life
3. Reveal chemistry's role in society
4. Have a low content base
5. Be within information processing capacity
6. Take account of language and
7. Aim at conceptual understanding

8. Offer genuine problem solving experience
9. Use labwork appropriately
10. Involve appropriate assessment'

A threshold concepts-centred curriculum would be a curriculum with a minimal but meaningful content list, would be easy to process by students, and would allow the understanding of key concepts by students.

## Concluding Remarks

Although the benefits of a threshold concepts-centered curriculum appear to be a promising strategy to prevent dropout, to the best of my knowledge such strategy was not proposed up to now. The grounds for proposing a threshold concepts-centered curriculum as a strategy to reduce drop out are:

a. It was already repeatedly confirmed that curriculum has a significant influence on students' success and retention;

b. A threshold concepts-centered curriculum would facilitate deep learning, which would result in students' success and retention;

c. The process of identification of threshold concepts with students would result in students being actively engaged in the process of curriculum engineering. Engagement of students is one of the important factors playing a role in students' retention.

d. Several concepts in chemistry fulfill the requirements to be threshold concepts and hence, it could be concluded that a threshold concepts-centered curriculum could be pivotal for chemistry students' success.

Nevertheless, students' success and retention is a result of the interaction between numerous factors and providing a threshold concepts-centered curriculum would not suffice as a strategy for students' retention.

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