A Critical Analysis of Trends in Student-centric Engineering Education and their Implications for Learning

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***Abstract*— Student-centric education has emerged as a dominant aspect of Higher Education policy over the last two decades. Much has been written about the benefits of student active educational approaches, and applied educational research, for instance the meta-study of Hattie, places emphasis on student-centric learning practices that enhance achieved learning outcomes.**

Most existing studies have been evaluations of single courses. In contrast this study focusses on the complete study context of the learner, who typically is in the situation of reading two or three courses simultaneously.

Our primary goal in this paper is to explore potential challenges as we attempt to scale up active learning to encompass the full curricula. We use a mixture of interview and survey data collected from staff, combined with course schedules and student input to explore some of the potential implications of mandating a student-centric approach over an entire curriculum.

INTRODUCTION

The trend towards student-centric and student active learning in higher education builds on an increasingly influential body of work in the higher education research literature (see figure 1) [1]–[4]. Arguably this trend started to gain momentum after the early work on deep and surface learning approaches started to shift focus from what the teacher did, to what the student did, and how the student approached learning. We see early arguments for adopting a student-centric approach in the seminal work of Gibbs and his colleagues [5], [6] in the 1980s.

The emergence of the scholarship of teaching and learning movement, sparked by the publication of Boyers book in 1990 [7], had a profound effect on university leaders and management. An increased focus on the educational side of the academic profession lead to efforts to restructure teaching efforts to align better with a focus on student learning outcomes rather than the historical focus on content. This shift from conceptualising teaching as the transmission of information to a more student-centric and conceptual change focused practice was further reinforced by Prosser and Trigwell when they published the Approaches to Teaching Inventory [8] (ATI) in 1994. The ATI uses earlier research to develop an instrument that can be used to assess the conceptual focus of university staff in their teaching practice. The validation of the ATI survey instrument uses open factor analysis to arrive at a best fit two factor model which divides conceptions of teaching into two primary classifications concisely described as teacher-centric with an information transmission focus and student-centric with a conceptual change focus.

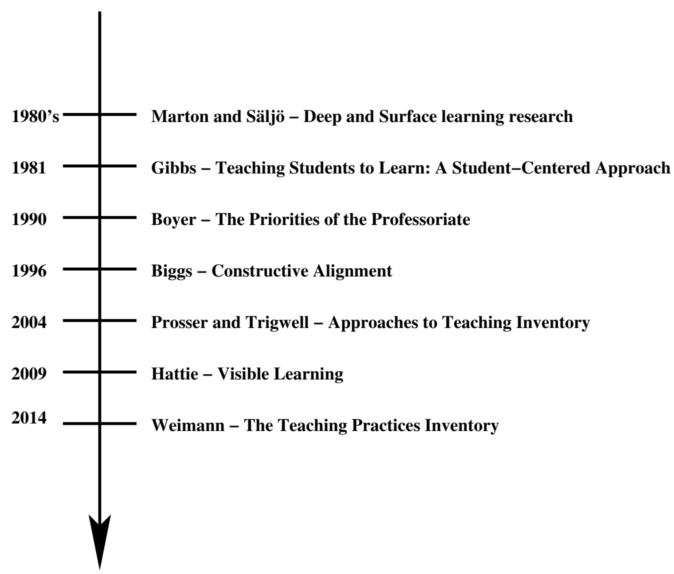

FIGURE 1. Trends in higher education policy and practice

More recently influential voices have been raised advocating widespread adoption of student-centric and active teaching/learning methods. This type of reasoning is bolstered by statements, such as the following, which can be found in a recent paper published in Nature [9] where the authors make the following statement.

> "Last year, a group led by biologist Scott Freeman at the University of Washington in Seattle published an analysis of 225 studies of active learning in science,

technology, engineering and mathematics (STEM) and found that active learning cut course failure rates by around one-third. ‘At this point it is unethical to teach any other way,’ declares Clarissa Dirks, a microbiologist at the Evergreen State College in Olympia, Washington, and co-chair of the US National Academies Scientific Teaching Alliance, an initiative to reform undergraduate STEM education.”

Large scale meta-studies, such as those of Hattie [10], [11] and Freeman [12], as well as teaching task forces such as those of Duff in the UK consistently demonstrate considerable learning outcome benefits, typically quoting pass rate improvements in the range of 20-30%.

However, the impact of considering the broader educational context on the results obtained in existing research studies remains largely undocumented and unexplored. In most higher education systems students take several courses concurrently during the course of an academic term. This means that students are engaged in parallel study activities in up to three or four courses at any given time, with the concomitant likelihood of timetable clashes, and an increased probability that they will have multiple assignment deadlines which fall in a single week.

Exploration of the impact of the increasing emphasis on student-centric learning is extremely timely. University policy documents codifying targets for student active learning are increasingly common. At Uppsala University, Sweden the University council recently approved a goal and strategy document which provides very clear directives.

> Goal: Ensure that a significant percentage of courses in the degree programmes offered by the Faculty of Science and Technology are student-centric and student-active.
> Action plan: The Faculty commissions an inventory of teaching and learning approaches. Based on this overview degrees with limited student-centric material will be required to revise their curricula and courses with the intention of introducing a higher degree of student-active content.
> A short in service training course acquainting teachers with the importance of student-centric and methods for engaging in student-centric education will be developed and made available to all teaching staff. The goal is for all staff to have taken this course within three years of it being offered for the first time.

What consequences can be expected of this type of large scale policy change in teaching practice? We are concerned that the rapid time-lines for implementation can be expected to place significant pressure on staff to rapidly redesign their courses. This paper explores a number of areas of concern that can arise when a tertiary institution makes a rapid transition from the traditional lecture, assignment and examination course structure.

Many traditional course designs clearly placed fewer constraints on student time management than a course with a typical active learning based instructional design. This raises questions about the implications of adopting some typical instructional techniques that are often linked to active learning, in particular compulsory attendance and summative continuous assessment.

Study Design

To provide a wide range of perspectives on student active learning this study draws on three major data sources, as shown in Figure 2.

Data type	Sample size	Location	Duration
Student schedules	3 courses	Uppsala	N/A
Staff interviews	4	Uppsala Linköping	20 min
Academic Staff Survey	139	International	N/A

Figure 2. Study data

To provide a richer context for the study, and to gain more insight into how our staff experience to pressures to adopt new instructional methods, we conducted three interviews as part of a staff development discourse during the 2015 academic year. These discussions generally ask staff to reflect on their teaching activities, and identify the things that have worked well, as well as spending some time on potential issues and areas for improvement. We conducted one interview outside our local context in order to discover if similar trends were being experienced by colleagues in other Swedish universities.

To investigate what teaching practices academics associate with the term active learning, a pilot survey was conducted in April, 2016. Basic demographic data was collected to establish the region, age and educational role of the participants. The main survey consisted of a single question, Please list between three and five teaching and learning practices that come immediately to mind when you hear the term ”active learning”?. The survey intent was to elicit the respondents spontaneous associations with active learning as educators.

Results and Discussion

I. *Academic Staff Survey*

This paper analyses the first 139 staff survey responses. These responses were collected over a two day period following postings to social media groups, and the ACM SIGCSE mailing list. The poll was kept open for a further two months in order to get a better response coverage for subsequent research. Each of the 139 responses contained 3-5 items connected with active learning.

Some responses are quite descriptive and relate to the desired outcomes that the teacher has in mind, for instance the response from Betty below.

> “ Student-centred focussing on where the student is and where you want them to be; practical activities

> for students; learning through question and answer; experiential learning ”

Joan is more concrete in her response, giving examples of specific teaching and learning interventions that might be applied to enhance the active learning content of her classes.

> “ clickers, peer instruction, team based learning (and inquiry based, project based and problem based learning), communication training with formative assessment, and reflection exercises for self-awareness ”

A few responses deal with more general educational principles and goals.

> “ Grounded in cognitive constructivist learning theories, novice programming and visualization environments proceed from the idea that learning is a process in which one constructs ones own understandings through active engagement with ones environmentand, especially through constructing and exploring ones own artifacts. Thus, I think of environments that enable learners to construct, view, and interact with concrete visual representations of the computing processes they are studying. ”

The majority of the survey responses are from Europe, roughly 50%, North America, almost 40%, and Australasia/Pacific, just under 10%. From Africa, Asia, and South America we only have four responses. This is probably an effect of how we distributed the survey. Distribution via personal and institutional social networking channels and mailing lists (for instance the ACM SIGCSE mailing list) and to teachers at Uppsala university were effective ways to garner responses for a pilot study, but focused data collection on the academic populations well represented in those venues.

The teaching experience among those that responded is evenly spread, with roughly a third each for the spans 0-10, 11-20 and over 20 years engagement in tertiary teaching. Of those that answered over 80% were university teachers (lecturers or assistant/associate professors, depending on the academic system to which they belonged), almost 15% were PhD students, and about 5% were something else, e.g. sessional teachers or retired.

Due to the complexity of the responses we have separated compound statements and extracted the key terms in each of the free-text responses. After separating and cleaning the data a total of 511 associations with active learning were extracted as separate items. We then applied a data driven qualitative analysis approach to thematically cluster the survey items. The analysis uses a grounded theory approach and consisted of four cycles of analysis conducted the authors in which clusterings were identified and critiqued following Mayring's inductive content analysis approach [13]. Initially two of the authors studied the data independently after which they suggested initial categorisations. These were then negotiated to form a common categorisation. The final set of categories is based on an iterative and collaborative analysis process where all three researchers participated. In each analysis cycle we revisited the 511 items and associated them with one of the thematic frames. Data that fit poorly into the current framework were discussed among the authors resulting in revisions and extensions which incorporated the data more fully into the analytical structure.

II. Survey Analysis

The thematic classification of the data identified 25 items which directly describe what the respondent associates with the term active learning. The most common theme among these is student active participation and engagement. Some express this through negative associations expressed as a desire to help students not to engage in practices that were seen to be a *waste of time* or *redeveloping the wheel*. Four items focus on the teacher and teaching roles and practices, e.g., *Professor is a coach or guide in learning vs the sage on the stage.* or *To successfully implement active learning requires a cultural change in the professoriate and proper training of the teachers.*

Two responses are tangential to the question. One of these deserves a response, *Where is the ethical permission/agreement for collecting this data?*. We note that, since no personal data were associated with responses, no ethical approval was required under Swedish Law to collect the data used in this paper.

The remaining 480 items describe teaching methods and practices that the respondents associated with active learning. In the categorisation process we found that there were groupings of items that could be seen as categories forming a few major domains. The domains we identified were: 1) Granularity of intervention, 2) Time management, and 3) Intrinsic motivation. Those are expanded on below, where it is important to note that a single item can be associated with several categories in a domain and normally also belong somewhere in each domain.

1) Granularity of intervention: The teaching method items describe interventions of differing scope and granularity, ranging from, using a minute of lecture time to ask a question, to, altering the structure of an entire course. Figure 3 summarises this domain, observed that most items fall into the integrated category. Since part of our argument is that rapid deployment of integrated approaches to student-centric active learning can have undesirable side effects on student learning it is interesting that less than half the suggested items fell into the isolated/limited category. This suggests that it is indeed important to consider the student learning environment more holistically.

2) Time management: The aspect of interest in this domain is an association with helping students to manage their study time. This theme deals with terms that are indicative of teaching methods and assessment that can direct where and when student engage in learning activities, and what they do in that time to this domain. The data in Figure 4 show that a vast majority of the suggested items relate to some form of task. To note in the context of this paper is that tasks are something that is naturally assessed and thus associated with a deadline.

Category	Explanation	Examples	Items
Isolated/ Limited	Inside a teaching session	Clickers, think-pair-share, live coding	216
Integrated	An assignment or a teaching session	Seminars, problem solving, pair programming	334
Holistic	A course or a part of a course	Open ended group projects (OEGP), process-oriented guided inquiry learning (POGIL)	164

FIGURE 3. Granularity of the intervention

The categories belonging to this domain describe interventions aimed at increasing students intrinsic motivation. The interesting aspect here is the different approaches used to achieve this overall goal. We identified two different approaches to increasing intrinsic motivation of students, those where different kinds of interaction are used, and those which aid students in developing motivation in relation to their learning.

Category	Explanation	Examples	Items
Tasks	What (and when) - Giving students specific questions or tasks to solve	Assignments, exercises, projects, learning by doing	396
In-class	What, when and where - Making students be at a specific place at a specific time	Lecture, tutorial, workshop, labs	198
Out of class	What (and when) - Influence what students do when they are not in classes	Flipped classroom, homework assignments, pre-class quizzes	45

FIGURE 4. Managing student's time

3) Intrinsic motivation: Managing student motivation also emerged as an important focus for many staff. Two primary clusters of techniques emerge from our data analysis. One cluster focusses on patterns of interaction which promote active student engagement, the other focusses on providing students with identifiable learning goals, in the hope that this will stimulate their levels of motivation.

a) Interaction: The items in the intrinsic motivation domain almost all rely on some sort of interaction and the categories in this group capture different aspects of the interaction intended. The interventions listed in Figure 5 support the view that many members of the academic teaching profession focus on student-to-student interaction in student active teaching settings.

Category	Explanation	Examples	Items
Collaborative	Students collaborate with other students	Peer instruction, discussions, teamwork, projects	396
Dialogue	Students interact with teachers or learning resources	Clickers, think-pair-share, workshops, seminars, discussions	156
Interactive-environment	Students interact with the environment, "the real world"	Discovery based learning, excursions, exploration	9
Visual Kinesthetic Auditory	Students interact using other senses than in the traditional read/write learning	Kinesthetic activities, manipulatives, labs, CS unplugged	36

FIGURE 5. Motivation through interaction

b) Engagement and Motivation: Staff survey items dealing with developing a sense of intrinsic motivation can also be clustered based on the type of motivation envisaged. Figure 6 illustrates that another common approach is to leverage the sense of satisfaction associated with constructing something, whether tangible or abstract. Also staff clearly value creating a social or professional context in which learning takes place.

AN OVERVIEW OF THE SURVEY DATA

The most common individual practices mentioned were group work (43 items), project work (41 items) and peer instruction (40 items). These methods are all collaborative and constructive, but do not necessarily involve interaction with a teacher. Flipped classroom, which requires interaction with teachers and address students out-of-class behaviour was also commonly mentioned (37 items).

In-class activities require the presence of students and teacher and can thus induce requirements on scheduling, especially if participation is mandatory and linked to summative assessment. Task driven activities are also often linked to assessment to increase student participation and provide extrinsic motivation. Many methods establish an attendance and prior preparation requirement since their success depends on the students coming well prepared. An example of this is the flipped classroom, where preparation is essential in order for the contact sessions with teaching staff to have the intended effect.

How does this affect student perceptions and the student study environment? We consider this from the perspective of a degree programme student who is studying full time. A typical student study timetable with associated summative assessment items is discussed in the following section.

Category	Explanation	Examples	Items
Learning the craft/trade	Connects to the real world and the students future profession	Students doing research, experiential learning, learning by doing, case studies, pair programming	164
Constructing	Construct an artifact or synthesize knowledge	Learning by doing, labs, discussions, problem solving	377
Competing	Competition is used to encourage higher performance	Competitions, debates	3
Self-directed learning	Responsibility and control is moved from teacher to student	Process-Oriented Guided Inquiry Learning (POGIL), students doing research, act as tutor	26
Developing self-awareness	Students learn about their own competence in relation to their subject of studies (encourages self-directed learning?)	Pair programming, act as tutor, discussions, flipped classroom, reflections	106

FIGURE 6. Engagement and Motivation

STUDENT SCHEDULES AND WORKLOAD

In the last decade, the use of student activating teaching practices has increased dramatically in our institution. The latest trend is that final exams are replaced by continuous summative assessment, assignments spread evenly throughout the duration of the course. These assignments often occur frequently, sometimes several times every week, inducing a lot of deadlines that students have to meet. When several such courses are run in parallel, students may end up with several deadlines every day. Each of them small and insignificant when viewed separately, but together they cause students a lot of stress and prevent them from gaining experience in independently planning their own time and studies.

Figure 7 shows the plan for a typical week for a student taking two courses with continuous assessment in parallel with a more traditional course. Mandatory classes and deadlines have been marked with boldface. In italics, we show the students estimation of what topics need to be studied in order to meet the next deadline. Deadlines 1, 2, 3, 6, and 7 are small assignments designed to ensure that the students have prepared for the next class. The assignments are small, but one has to remember that they are connected with the actual preparation, typically reading and understanding course material, which takes some time. Deadlines 4, 5 and 8 are for larger assignments, two of them are programming tasks to be done in groups and one is a more theoretical assignment. For one of the group assignments, the students also have to form groups themselves.

As is clear from the figure, in order to pass all three courses, a student has to be active nearly continuously over the entire working week. What it also shows is that the frequent deadlines regulate quite specifically what topics the students have to focus on when they are not in class. There are very few hours per week that the student can choose to invest in independent, self-directed study, learning more about a topic which piques their interest.

	Monday	Tuesday	Wednesday	Thursday	Friday
8				*Networks*	Lecture: Databases
9	**Deadline 1**				
10	**Seminar:** Semantics	**Workshop:** Networks	Lecture: Databases		**Workshop:** Networks
11					
12			**Deadline 3**	**Deadline 5**	
13	Lecture: Databases	Lecture: Databases	**Seminar:** Semantics	*All courses*	
14					**Deadline 7**
15	*Networks, Semantics*	*Databases, Semantics*	*Networks, Semantics*		**Seminar:** Semantics
16					
Night	**Deadline 2**		**Deadline 4**	**Deadline 6**	**Deadline 8**

FIGURE 7. Simplified student timetable

Another aspect is the number of context switches inherent in this division of the student's time over the course content in three subjects. Following this timetable requires the student may have to work on two different topics in a single two hour period. For larger programming assignments, it is almost impossible to be productive in such a short timeframe. Some students may even benefit from spending an entire week focusing more on one topic to focus on another the next week.

TEACHER INTERVIEWS

This type of teaching and learning approach presents increasing challenges in other parts of the academic system as well. Situations in which clashes occur between compulsory course components in parallel courses have become increasingly common. A typical scenario is described by Albert who is degree programme coordinator at a large Swedish university with a profile in engineering.

> Albert: ...and so after a few weeks students started to complain about the workload. I called a meeting with the teachers and we discovered that students had up to 15 hand-in exercises a week in the courses running in parallel that term. Everyone had decided to use continuous assessment approaches, and suddenly the students were inundated in deadlines.
> Interviewer: So how was that resolved?

> Albert: The solution was to agree that no one would have more than two hand-in exercises a week in any course. It worked then, but that was a few years back. I wonder how it is now, we have not looked at the situation recently.

Unlike traditional lectures, many student-centric teaching methods are designed for teaching in smaller groups. For large classes, each such activity has to be repeated multiple times and thus uses a considerable amount of schedulable time. When several courses with such activities are run in parallel, scheduling them without clashes is challenging. Occasional clashes may be acceptable unless the scheduled educational components are compulsory, which is often the case when continuous assessment is used.

Teachers may experience a pressure to use student activating teaching methods, even though their teaching works well in traditional lectures. The book ”The Courage to Teach” by Palmer [14] is an interesting read with regard to teachers teaching in a manner foreign to their identity. Palmer argues for the case that the most central aspect of good teachers are that they use methods that are ”true to themselves, which he claims is far more important than which didactic methods they use. This aspect is worth considering in the light of demands for using a particular method, or cries for banning lectures [15].

SUMMARY

Continuous assessment approaches often lead to demands that students are present at teaching sessions in order that their learning can be directly observed. One implication of this can be that a large proportion of the working week consists of timetabled course activities, leaving students with little or no time for reading course literature and engaging in other forms of self directed study. Self directed study was historically expected as a part of the learning behaviour necessary to pass courses, and students in many disciplines had around 12 to 14 hours of timetabled activity per week. However, since the early 1990s scheduled class time (teacher contact hours) has been seen as quality indicator in higher education, with the result that many degree programmes have very dense timetables.

Our analysis of teacher associations with student active learning accentuates this concern. Many of the practices referred to have implicit links to increased compulsory attendance and in class continuous assessment. Although many of the student-centric learning and activating teaching methods mentioned by staff when responding to our survey are useful to increase learning in isolated courses, they may pose a threat to students developing independent learning skills if used broadly across the curriculum in many courses. When students are activated as a result of including scheduled tasks throughout their school days, they lose the incentive and the opportunity to plan self directed learning activities, and are correspondingly disempowered when it comes to regulating their own learning.

The Overstuffed engineering curriculum has been a topic of debate for several decades [16]. Traditional teaching and assessment practices traditionally target a subset of the material included in the course description. The assumption was that students, as a result of self study, would acquire a more complete knowledge base covering the remaining material. The motivation for students to engage in additional reading and learning outside formal instruction was due to the inherent uncertainty associated with the assessment choices made by lecturers. Quizzes and final examinations examined the full range of course material included in the course description, not just the content covered in the lectures and practical work associated with the course.

When staff are put under pressure to adopt student active teaching methods might this result in a tendency to increase compulsory attendance and fine grain assessment, in their efforts to enhance the student active/student-centric nature of their courses?

Some evidence for this seems apparent in our classification of survey responses. Staff associations with active learning imply that their natural tendencies when confronted with demands to increase student active learning content are likely to trigger wholesale course restructuring and increased focus on managing student time through continuous assessment strategies. Given the potential consequences of a shift to large scale use of continuous assessment and the already overstuffed nature of engineering curricula we emphasise the importance of taking an holistic stance as we initiate broad ranging higher education reforms aimed at promoting student active pedagogies in all teaching.

CONCLUSIONS

Research shows that implementing a student-active curriculum clearly has many advantages for student performance in individual courses [12]. Clearly tertiary education has the potential to benefit considerably from a move towards a more student-centric and student active approach to student learning. However, it is also important for heads of department and directors of studies to be aware of the potential pitfalls associated with widespread use of some common student-active classroom techniques.

There are significant challenges associated with deploying the currently prevalent models of student active classroom learning across a whole curriculum. Such challenges include, exposing the overstuffed nature of the engineering curriculum, difficulties in establishing clash-free class schedules, and high cognitive and study stress levels in the student population.

Our research results reveal patterns of association within our profession. While the scope of the interventions might vary we can demonstrate that there are strong associations between terms such as student-centric teaching and active students and techniques: continuous assessment, flipped classroom within our profession.

Our qualitative data suggests that a residual uncertainty, even amongst innovators, in the validity and reliability of formative and alternative assessment strategies may lead to an emphasis on mandatory participation in many settings. This can be argued to have a negative impact on student autonomy and self-directed study practices, as well as having pragmatic implications for class timetabling.

Our findings provide an informed platform for future efforts in widespread deployment of student active learning in Engineering. Clearly some of the educational practices associated with student active learning present logistic and administrative challenges. In some cases these practices can be in partial conflict with regulations and legislation that build on outdated pedagogical assumptions (e.g. The Swedish right to re-examinations several times per academic year). We also call for additional research which more fully explores the holistic impact of the widespread introduction of active and student-centric learning approaches in STEM disciplines.

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