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Simplify! using self-determination theory to prioritise the redesign of an ethics and history of technology course

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ABSTRACT
A course on ethics and history of technology, taught to 1886 first-year engineering students of 14 engineering departments was redesigned using Self-Determination Theory (SDT) by adapting many course elements at the same time. We applied the situational level of Vallerand's hierarchical model, analysing how the elements of this ethics and history course influenced basic needs and motivation in a mediating role, which influenced in turn course outcomes. Regression analysis demonstrated the central role of *competence* in the *assignment* for *intrinsic motivation*. A complementary qualitative analysis showed strong polarisation between different types of students and indicated many remaining challenges. We conclude that the Vallerand model was a useful tool for prioritising redesign in this course. We suggest further research in the use of this model, on the role and meaning of competence and on the role of frustration, in ethics and history courses in particular and engineering courses in general.

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Self-determination theory; engineering ethics; competence; hierarchical model; frustration

1. Introduction

It is broadly recognised that engineers of the future should combine a depth of expertise and deep disciplinary knowledge with the ability to engage with other experts across intellectual and disciplinary cultures (Conley et al. 2017). Engineering problem-solving increasingly lies on the societal, human or ethical side of engineering practice, requiring new approaches within the engineering education curriculum (Grimson 2002). Teaching humanities and ethics to engineers is therefore important, but also challenging (Newberry 2004).

Different universities apply different approaches about how to motivate students for humanities courses in their educational programmes. Some focus on particular ethical theories such as virtue ethics. Harris (2008) argues that virtue ethics provides a greater place for discretion, judgment, inner motivation and commitment than other approaches. He concludes that humanities and social sciences are crucial in the professional education of engineers. Han (2015) finds that virtue ethics and positive psychology can effectively create motivation for self-improvement by connecting the notion of morality and eudaimonic happiness. Iseda (2008) focusses on professional pride to motivate engineers to do excellent work. Other approaches focus on parts of the curriculum to motivate engineering students for ethics. Steele (2016) demonstrates the need for a moral component for science education and pleas for a collaboration between STEM and ethics education to increase student enjoyment and motivation for their science studies. Rodzalan and Saat (2012) show that a

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focus on moral and professional ethics as part of a set of generic skills increases student-motivation. A third group of research focusses on educational methods to motivate students. Dym, Rossmann, and Sheppard (2004) find that design activities can motivate and enhance the place of values and ethics in undergraduate curricula. Gupta (2015) expresses that value education enables the development of a 'holistic' mindset that can be realised by action-oriented programmes. This is also described by Abulencia (2011) who motivated students by integrating a real-world engineering ethics case study into a Senior Unit Operations Laboratory course and by Mukherjee and Purkait (2011) who linked professional ethics issues with a basic mobile robots workshop. Within this third group of educational methods, Herman et al. (2012) developed a 'low-cost Course Design Method' to create a shift towards intrinsically-motivated students who experience positive learning experiences at low cost to the faculty. As a generic method, it should also be valid to ethics and history courses in engineering education.

We took this third approach as our starting ground when we focused on a mandatory introductory course on History and Ethics of Technology that was taught to all first-year's engineering students of a Dutch technical university. We report on an analysis of a course redesign to understand the core issue of the course. We first give the context of this study and elaborate on the hierarchical model of Robert Vallerand within Self-Determination Theory (SDT) including motivational types and basic needs. We then describe our SDT-based redesign and our research questions. We inquired how we can understand the relations between course elements, basic needs, motivation types and course outcomes in the USE basic course based on SDT insights using Vallerand's model, and if this analysis could provide prioritisation for the redesign. We further explain the mixed method approach and describe our results. The inquiry showed that the students' perception of the *assignment* strongly influenced their *competence*, which in turn proved to be of central importance for students' *intrinsic motivation* and *identified regulation* and this eventually influenced *overall course evaluation*. This was a helpful insight as it allowed to prioritise our redesign efforts. Self-determination theory helped to shed light on student motivation in our ethics and history of technology course, but careful attention was needed to the underlying assumption about students' needs and how these could be linked to various course elements. We suggest further research in the role of *competence* and frustration in ethics education in engineering curricula.

2. Context of the study

Engineers of the future should combine a depth of expertise and deep disciplinary knowledge with the ability to engage with other experts across intellectual and disciplinary cultures (Conley et al. 2017). Engineering problem-solving increasingly lies on the societal and human side of engineering practice, requiring new approaches within the engineering education curriculum (Grimson 2002). A medium size technical university in the Netherlands offers its students four courses of 5 ECTS (European Credit Transfer System) each on the topic 'User, Society and Enterprise (USE)'. The aim of the USE-component of the bachelor programme is to raise awareness of the social and cultural consequences of user, society, and enterprise aspects of technology and help students to understand the societal dimensions of technological developments.

The USE-component consists of two parts: in the first study year, all students follow a compulsory introduction to USE covering ethics and history of technology (USE basic course). In their second or third year, students choose a USE course sequence from a list of 16 themes, such as e.g. *Decisions Under Risk and Uncertainty, Patents and Design Rights and Standards, Robotics Everywhere, Quality of Life,* and *Technological Entrepreneurship* (Bekkers and Bombaerts 2017).

Within such a course sequence of 15 ECTS, students work their way into disciplines from the social sciences and apply this knowledge and these skills in an interdisciplinary way, as they work in groups of engineering students from different departments. It is a fundamental choice made by the university to offer this type of education in the bachelor years. Offering it only later as part of the master programmes would make the USE education seem more like an additional piece of knowledge and not as an integral element of what all engineers of the future need to know about their field and the effects of technology on society. As such, the university states that 'engineers of the future must be professionals capable of thinking critically and independently […] they must be able to contribute to solving societal problems […]. They must have an inquiring and creative attitude, a high degree of creativity and societal responsibility' (Meijers and Brok 2013).

In our study, we focus on the USE basic course that teaches students to identify the societal aspects of technology along the dimensions of users, society and enterprise. History of technology is used to identify these societal dimensions in concrete case studies, and to help students understand where the engineering profession is coming from and where it is going. The historical part of the course also covers topics such as techno-optimism ('age of promise') and techno-pessimism ('age of crises') as well as technocracy and participation. The history part is followed by an ethics of technology part helping students to identify the underlying values and value conflicts that surround the development and implementation of technologies in societies and that often lie at the heart of disagreements between stakeholders. Students acquire knowledge in basic ethical terminologies such as 'values in design', 'risk' and 'shared responsibility'. After the course, students are furthermore able to analyse and evaluate design choices in light of three major western ethical traditions: virtue ethics, utilitarianism and deontology.

The USE basic course is taught in the first year of the bachelor programme to all 14 major programmes from the different engineering departments of the university. The audience of the course is thus very diverse, covering e.g. students from Applied Mathematics, Software Science, Medical Sciences, Chemical Engineering, Industrial Engineering, Built Environment or Sustainable Innovation to name a few.

Quality is a broad concept (Bombaerts, Doulougeri, and Nieveen 2019). Here we focus only on a few consequences. Students' comparison between the effort they have applied and the number of credits of the course indicates that they assessed the *rigour* of the course as low for several years, which has been an internal debate at the university. Student *enjoyment* and perception of *relevance* throughout the course always has been a major factor for the student's evaluation of the course. Also the overall *course evaluation* was reported as low in the previous versions.

3. Theoretical background: Vallerand's hierarchical model in SDT

One of the main aspects for the redesign was thus to focus on students' *enjoyment*. This item does not measure mere 'fun'. It is linked with intrinsic motivation as described by Self-Determination Theory (SDT) (Ryan and Deci 2000a). This was the main reason why this theory was chosen, next to its cumulative and empirical evidence in higher education and the availability of standardised and validated measurements (Vansteenkiste and Soenens 2015). The research of Herman et al. (2017) also promises that SDT can be used for scalable and low-cost redesign to increase students' intrinsic motivation.

In this section, we explain the hierarchical model of Robert Vallerand that describes how basic needs and motivational types link together with situational factors and situational consequences. We first elaborate on the three basic needs and the five different motivation types as they are conventionally used in SDT and then describe how these are used in Vallerand's model.

3.1. Basic needs

SDT states that motivation is determined by basic needs, defined as – 'energizing states that, if satisfied, conduce toward health and well-being' (Ryan and Deci 2000a, 74). SDT reveals three central basic needs: autonomy, relatedness and competence (Deci and Ryan 2000; Ryan 1995; Ryan and Deci 2000b). Autonomy should not be regarded as feeling of complete independence or the freedom to do whatever one likes. Rather, it refers to having meaningful choices (Van Petegem, Vansteenkiste, and Beyers 2013) which always needs structure (Bombaerts et al. 2018). Reeve (2009) indicates several aspects of an education process that supports the autonomy of the students. Amongst these aspects are the pleasure linked to the tasks given, the ability of the students to contribute to the course organisation, and the availability of explanation or elucidation. The magnitude of the course more than the fact that it is an ethics course, is a challenge here, since it is very difficult to make students contribute to the course organisation. Whereas autonomy refers to the individual, relatedness refers to the need to be connected to others. Relatedness can be supported in educational settings if students experience the behaviour of teachers as being 'present', acting with responsivity and emotional warmth. Although many teachers have both, an engineering and a human science degree, they report that students often do not relate to them via the topic. Competence, finally, refers to the need to experience mastery and be successful in challenging situations and activities. Activities should be challenging, but not too difficult in order to allow students to still experience being in control (Reeve 2009). Students struggle here, since they have difficulties reading ethics texts, but also report that the ethics course does not challenge them.

Basic needs in Engineering Education can give more substantial information about the reasons why courses are perceived as more or less motivating. Several studies, not in ethics, have highlighted the link between basic needs and engineering students' motivation. Gero et al. (2016) found that competence can be supported by a teaching that is challenging enough, but not too challenging. Relatedness was met in their study due to the personal acquaintance of students with the faculty members. Honkala et al. (2015) illustrate how collaborative learning methods can positively influence students' autonomy, relatedness, and competence. Gero and Mano-Israeli (2017) report that for practical engineering students, competence was not fully met in a course because the students were unable to cope with the study materials. Similarly, the need for relatedness was not completely met because of the distant behaviour of some of the teachers. While the above-mentioned studies used a qualitative approach, Koh et al. (2010) illustrated quantitatively that their control group had significant less autonomy compared to a group in 3D simulation-based learning, but that relatedness and competence were not significantly different in the two groups.

3.2. Motivation types

SDT states that basic needs influence different types of motivation. It puts these motivation types on a motivational continuum (Ryan and Deci 2000a, 2000b). All types will be present simultaneously but in different proportions. In our study, we focus on engineering students in ethics courses, but SDT of course holds for all human beings in all situations. Firstly, *amotivation* is the motivation type on the lowest end of the continuum. Amotivated students do not report any intention to perform a given task. Furthermore, amotivated students often do not worry too much about reaching the learning outcomes. Some students report that they consider the ethics course as completely irrelevant and are sure they will pass it without too much effort. Secondly, students can be *externally regulated* to do something. In this case, they engage in a given activity because of an external driving force or in light of external pressure. They perform a task because they feel forced by the course set-up (teachers, tutors, examination system) to do so. An example here is that some students report to have problems expressing their interest in the course because they experience external peer-pressure to mention that the course is 'not cool'. The third motivation type is that students have *introjected regulation* and act based on internal pressures. A student can feel internally driven and feel the internal demand to study to maintain self-worth or answer her perfectionism. Students here choose a very narrow, result focused approach to succeed in their exams. An example for this is a student that studies for the ethics course only because he worries that a low grade will endanger a possible *cum laude* distinction. If students internally accept a reason for their behaviour, SDT defines this fourthly as *identified regulation*. An engineering student might not be very interested in ethics in itself, but she might acknowledge that ethics is essential for her future profession and will therefore be motivated to study ethics as part of her engineering training. Identified regulation requires self-endorsement, self-knowledge and a cognitive view about one's own functioning (Vansteenkiste and Soenens 2015). Finally, the motivation type at the other end of the continuum according to SDT is *intrinsic motivation*. Here students show enthusiasm for the task itself. An engineering student might simply enjoy reading ethics materials (Ryan and Deci 2000a). The different motivation types also allow researchers to calculate the *Relative Autonomy Index* (RAI), which is used as a single variable to express the overall quality of motivation (Sheldon et al. 2005; Vansteenkiste and Soenens 2015, 195) RAI = 2**intrinsic mot* + 1**identified reg* −1**introjected reg* −2*e*xternal reg*.

Comparing differences in types of motivation between different set-ups gives information about the motivational effectiveness of a redesign. Although again not applied on ethics courses, it is a common approach of SDT in Engineering Education Research. Gero, Stav and Yamin (2016) for example found that students' introjected and external regulation and their intrinsic motivation changed after a redesign introducing real world examples. Koh et al. (2010) did not find any differences in any motivation type between a control group and a group that was provided a 3D simulation-based learning method. Honkala et al. (2015) used SDT to show how students' RAI was weakly correlated with students' grades. These analyses are examples how engineering education research used SDT to give insight in redesign effectiveness.

3.3. Vallerand's hierarchical model

Robert Vallerand systemised in his hierarchical model (Vallerand 1997) how course design influences basic needs and motivation and how these two constructs influence course outcomes as satisfaction or grades. The model distinguishes between several levels. We focus here on the situational level that refers to the specific activity of a given moment in time (i.e. course elements at a certain moment in the course). The hierarchical model describes social factors that influence basic needs that in turn influence motivation that influence consequences as affect, cognition and behaviour (see Figure 1 for the situational level of the model).

The hierarchical model (Guay, Vallerand, and Blanchard 2000) is widely accepted for improving engineering education courses by linking to the situational factors (i.e. Gero & Mano-Israeli, 2017; Gero and Danino 2016; Gero, Stav, and Yamin 2016), designing contributing students pedagogies (Herman 2017), influence of project courses (Doulougeri and Bombaerts 2019) or providing scalable reform (Herman et al. 2012). Harnett (2012) focused on autonomy needs in engineering education and found many different factors that should be met (relevance, meaning, interest, application of the knowledge to practice, significant role in group decisions, lectures that are geared towards autonomy, and the provision of choice). The results of Koh et al. (2010) supported this when they found, in line with SDT, strong correlations between autonomy, competence, identified regulation and intrinsic motivation.

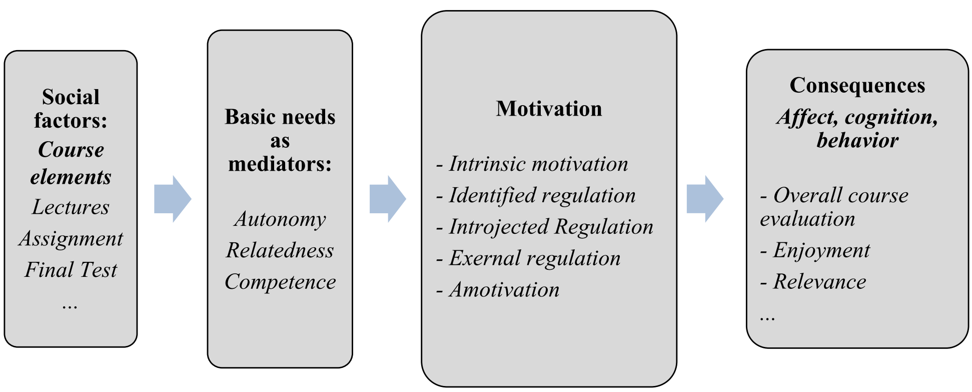

Figure 1. Social factors supporting basic needs as mediators and motivation types, supporting in turn consequences of affect, cognition and behaviour (Vallerand 1997, 274).

Vansteenkiste and Soenens (2015) described that competence related education consists of clearly communicated expectations, the availability of challenging tasks and the experience of trust before the learning activity. During the activity, process focused supervision and suitable help should be offered and teacher engagements should be preserved. Self-reflection should be encouraged and informational feedback should be provided after the educational activities.

In complex engineering courses, finding out basic needs support might demand prioritisation of what exactly has to be redesigned. Several inquiries gave examples of specific choices and precise changes. Trenshaw et al. (2014) found that critical incidents, such as the experience of failure, have a strong impact on competence and that therefore trust plays an important role. Nikou and Economides (2017) described the importance of the acceptance of mobile-based assessment and the role of basic needs as interim variables. They found that mobile device features had a small effect on students' autonomy and that educational material had an important effect on autonomy and competence. User profiles were found to relate to competence and teaching methods affected relatedness. The behavioural intention to use a system was predicted by two elements: perceived ease of use, importantly predicted by all basic needs and perceived usefulness for which autonomy was clearly the most important predictor. Vanasupa, Stolk, and Harding (2010) also modelled how course elements and personal traits influence psychological needs and motivation that influenced behaviour including engineering, history and art majors. They found that their 'Powerhouse' redesign was unsuccessful with respect to engagement, intrinsic motivation, perceived relevance and interest.

4. USE basic course redesign based on SDT

The USE basic course was redesigned with regard to the basic needs as described by SDT. We will describe below the overall course characteristics and the important changes that were made with regard to different course elements and how these changes refer to autonomy (A), relatedness (R) and competence (C). The general *course set-up* was not changed. The course was offered both in Dutch and in English, during nine weeks, in two different time-slots to accommodate the large number of students and the different languages of the different programmes (Bombaerts and Doulougeri 2019). For each of the eight streams a duo of teachers (one from ethics and one from history) was responsible and they guided a number of tutors and student assistants. In total, 32 tutors and teachers were involved. There were 8 parallel streams of the same course, each of which could accommodate about 250 students. Every lecture group of 250 students was further divided into four tutorial groups of about 62 students. The eight streams were grouped around 4 strategic domains of the university: energy, health, mobility, and data-science. For each stream, two subthemes were developed (e.g. 'Sustainable Energy Technologies' or 'Nuclear Energy' for the energy domain). Different cases were introduced per sub-stream to give students a choice (A), to make a link to the research and teaching topics within the university's community (R), and to stay closer to the potential interests of different students from different programmes (C). To further embed the course in the university environment, various events were organised and were publicly accessible. These events included screening of movies linked to the course topics (as the documentary film 'Citizen Four' directed by Laura Poitras, concerning Edward Snowden and the NSA spying scandal) or providing activities that consisted of discussion and commentary from ethics and history teachers on controversial topics (for example 4 lunch sessions on 'Diesel Gate'). These extra activities were meant to let students see the link between societal debates around emerging technologies and the content of the USE base course (R). These events should also be experienced as motivating and exciting.

The *course materials* consisted of two detailed study-guides and two books: an unpublished reader 'Engineering the Future, Understanding the Past' and 'Ethics, Technology, and Engineering. An Introduction' (van de Poel and Royakkers 2011). The first concerned all organisational and formal aspects of the course, and the second covered the different steps of the group assignment in detail. A university wide Moodle learning management system (LMS) replaced the former classical LMS that was only used in the USE courses. This change was intended to increase the recognition (R) with a familiar LMS. In this online system, we used a wiki platform in which all students wrote their assignments. All students could see the input of the other students of their tutorial. The idea was to be inspired by good ideas from others as a way to learn (R,C).

Each week, in each stream, students followed a *lecture* in a group of about 250 students. In these lectures, students gained knowledge of the relevant theories and insights from ethics and history. In the *tutorials* students worked in tutorial groups of about 62 students throughout the course in working groups of four or five. Tutor availability was regarded an issue in prior years. Therefore, *tutorial* time was increased from 1 to 2 h per week. A tutorial group (of 60 students) focused on one case enabling the tutor to use her or his own expertise (C) and therefore being more respected (R). Teachers were grouped to cases according to their research expertise, tutors were asked to become well informed about their case (if they were not so already, e.g. because of topics of their own Ph.D. thesis etc.). As such, the different student-groups worked within a tutorial group on one solution for one case. Tutorials used different interactive methods such as a small debate between different groups in week five to get students engaged with the topic and exchange their ideas and arguments from the ethical analysis (R,C).

The *assignment* was redesigned as well. Whereas in the past the history and ethics assignment parts were more isolated elements, in 2016 the 'ethical cycle' (van de Poel and Royakkers 2007) was extended to a broader USE engineering cycle to include elements from the history of technology component of the course in one interdisciplinary assignment. The group-size was reduced to three students per group to improve group dynamics and solve free-rider problems (R).

The *final exam* was still a multiple-choice exam, mainly due to organisational hurdles of grading 2000 students efficiently within a short amount of time at the end of the course. Three multiple-choice *interim tests* were added, to help students better prepare for the final multiple-choice exam (C). These tests were conducted online, such that each student got a randomised set of questions about different aspects of the course readings. The final exam accounted for 50% of the grade, the assignment for 40% and the interim tests for 10%.

In the 2016 version, the *peer and tutor feedback* were redesigned. First of all, students got a clear introduction about good feedback and what was expected from them. Students were asked to give peer feedback in the wiki four times during the course, and tutors gave feedback three times. These feedbacks were visible to other students, so students could also learn from each other. This was done to increase the feeling of competence (C), but also relatedness (R).

5. Research questions

The USE basic course was redesigned using SDT and Vallerand's model. Our objective was to understand how motivation and basic needs can play a role in the redesign. We therefore formulated the following two research questions.

(1) How can we understand the relations between course elements, basic needs, motivation types and course outcomes in the USE basic course based on SDT insights using Vallerand's model?
(2) Can this analysis provide prioritisation for the redesign?

6. Methodology

6.1. Data collection

Data was collected with an online questionnaire. One part consisted of the university's standard student evaluation of teaching taken after the final exam of every course. A second part added

Table 1. List of considered situational factors (course elements) with number of items per factor and one item as example.

Factor	#	Item example
Course set-up	3	'Do you feel that this course has achieved its learning objectives sufficiently?'
Course material	5	'Have the course materials, practice opportunities and interim tests/assessments contributed to the learning process/ability to pass the module?'
Lectures	3	'Are you satisfied with the lectures for example, structure, content, level, coherence?'
Tutorials	3	'Are you satisfied with the tutorials (for example, alignment with lectures, level, supervision)?'
Assignment	6	'The assignment encouraged me to try to understand the material'.
Final test	3	'Are you satisfied with the contents of the tests/ assessment, for example the level of the final test, reflection of the subject material, the relation between practice opportunities, interims tests and the final test?'
Interim tests	3	'The online quizzes added to my understanding of the subject matter'.
Peer feedback	3	'The peer feedback helped me to improve the assignment'.
Tutor feedback	6	'The history tutor feedback helped me to improve the assignment'.

feedback questions, basic needs, motivation and course evaluation items. The questionnaire asked about nine course elements as situational factors (see Table 1 for an overview).

Basic needs were measured with a basic needs survey (Ilardi et al. 1993). Eighteen items measured basic needs competence, relatedness, and autonomy of which nine are formulated positively (e.g. 'I felt a sense of accomplishment from the course work'.) and nine negatively (e.g. 'I felt pressured to do things in a certain way during the course'.).

The five types of motivation were measured with the 'Self-regulation questionnaire – Academics' (Vansteenkiste et al. 2009). It measured the five types of motivation (*intrinsic, internalised, introjected, extrinsic, a-motivation*) using four items with five point Likert-scales.

Course outcomes were measured at item level. We used the final *grade* of 2016 as an output variable. The *overall evaluation* was measured on a 10-point Likert scale ('On a scale from 1 to 10, how would you rate this course?'), *enjoyment* ('Have you enjoyed taking this course?') and *relevance* ('The USE basic course contributes to my development as an engineer'.) with a 5-point Likert scale. One item asked about the perceived *rigour* ('Do you feel that the number of credits (5 ECTS = 140 h) for this course (including teaching sessions, self-study, interim tests, and final test) corresponds to the effort you have applied?'). This item does not specify quantity or quality, but asks about rigour in an open, generalised and broad way. If students rated this last question a 3 on a 5-point Likert scale, it equals to what they think is the weight of a 5 ECTS course, which is considered optimal. If students assess the rigour lower or higher than 3, they consider the course easier than or heavier than 5 ECTS respectively.

Finally, students could also answer two open questions about what they liked and what they would like to improve about the course.

6.2. Participants and data analysis

With 646 respondents, the questionnaire had an acceptable response rate of 34.2% (Nulty 2008; Sax, Gilmartin, and Bryant 2003). Demographic variables gender, age and ethnicity were not asked for. Sampling bias on these variables could therefore not be calculated.

Cronbach alphas of the course elements were between 0.78 and 0.88. The factors of the five motivation types showed Cronbach's alphas between 0.74 and 0.90. For the eighteen ordinal basic needs items, the 18-by-18 polychoric correlation matrix of the data where negatively formulated items were recoded did not show a clear clustering of autonomy, relatedness and competence. Indeed, an ordinal confirmatory factor analysis (CFA) with a three-factor structure for the three supposed scales of the 18 basic needs items on the recoded data showed that this model had a poor fit ($\chi^2(132) = 1862$, $p < .001$, CFI = 0.689, TLI = 0.639, RMSEA = 0.147 and AIC = 28762, see the discussion section for an interpretation of this unexpected finding). Since the three subscales could not be validated on this dataset, we tested whether the three basic needs categories could be treated as bivalent; one dimension measured by the positively formulated items and one dimension measured by the negatively formulated items. A six-factor solution for the 18 original basic needs items indeed showed better fit to the data, despite increased complexity of the model ($\chi^2(120) = 762$, $p < .001$,

CFI = 0.884, TLI = 0.853, RMSEA = 0.094 and AIC = 27721), although arguably the fit is still suboptimal due to high correlations between items from different basic needs dimensions. Since further attention to this issue went outside the scope and aim of this paper, we chose to pursue this six-factor solution for pragmatic purposes and label the factors *aut+*, *rel+*, *comp+* for the three factors with positively formulated items, *aut−*, *rel−* and *comp−* for the factors with the negatively formulated items. The Cronbach's alphas and their 95% CI's were not strong but acceptable (Kline 2013): 0.67 (0.64–0.71) for *aut+*, 0.64 (0.61–0.68) for *aut−*, 0.79 (0.77–0.82) for *rel+*, 0.61 (0.57–0.66) for *aut−*, 0.70 (0.66–0.73) for *comp+* and 0.66 (0.63–0.70) for *comp−*.

After determining our scales, we performed stepwise regression analyses for each factor. All data analyses were conducted using SPSS and R. For the qualitative analysis, we performed a thematic analysis of the 602 open answers about what students liked and also 611 open answers about what students would like to improve about the course.

The uniqueness of our study lies in the in-depth analysis based on SDT and Vallerand's model and the thorough evaluation, based on a large quantitative and qualitative data-set. The redesign and the study systematically take the nine course elements into account. It develops a model to understand the influence of these course elements to basic needs and motivation types, and their influence on course outcomes like *relevance, enjoyment*, *overall evaluation*, *perceived rigour* and *grades*.

7. Results

7.1. Central role of competence in assignment

We performed stepwise regression analyses for each factor in the Vallerand model. The good collinearity diagnosis between course elements, between basic needs and between motivations types

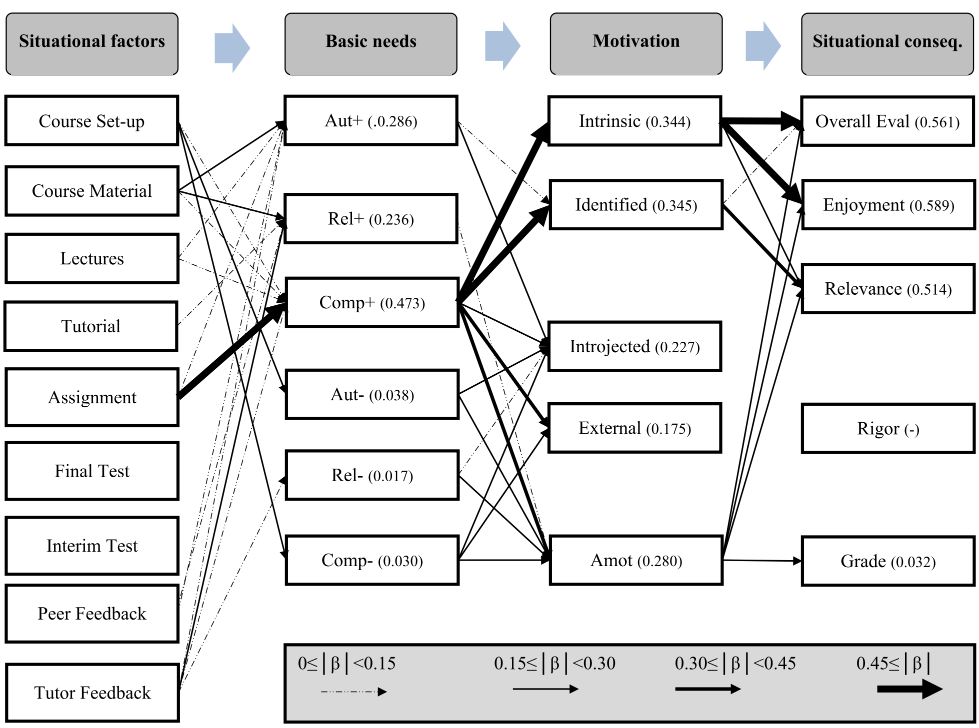

Figure 2. Overview of Stepwise Linear Regressions in Vallerand's model. Basic needs predicted by course elements, motivation types by basic needs and course outcomes by types of motivation. R^2 between brackets. │β│divided in four groups: 0≤│β│<0.15; 0.15≤│β│<0.30; 0.30≤│β│<0.45; and 0.45≤│β│.

guarantees an acceptable interdependence of the different predicting variables (Courville and Thompson 2001). The analysis (Figure 2) depicts a complex pattern of relations between the various elements. *Course set-up*, *course materials*, *lectures*, *tutorials*, *assignments*, *peer-* and *tutor feedback* all played a significant role in predicting the six basic needs factors. Similarly, all six basic needs factors played a significant role in the determination of the five motivation types. Three motivation types determined *overall evaluation*, *enjoyment*, and *relevance*. However, this web of complex interactions also let us to identify some principal influence relations. Figure 2 clearly showed the pivotal role of *comp* + . The students' evaluation of the *assignment* was by far its principal predictor. *Comp+* in turn was important to predict *intrinsic motivation* and *identified regulation*, which strongly predicted *overall evaluation*, *relevance* and *enjoyment*.

A closer look at Table 2 showed *aut+, rel+* and *comp+* were well predicted ($R^2 > 0.23$). *Course material* and *tutor feedback* were significant predictors for all positively formulated basic needs. Increasing students' perception of the *tutorials* and *peer tutor feedback* increased *rel* + . The factors with negatively formulated basic needs items were badly predicted.

Table 3 illustrated that motivation types were reasonably predicted by the positively formulated basic needs ($R^2 > 0.17$). Next to *comp+* as central element, we see that *aut+* and *rel+* were less important to predict motivation types. For *intrinsic motivation*, *comp+* was the only predictor, for *identified regulation, aut+* was also significant. *Introjected regulation* and *amotivation* were also well predicted by aut−, rel− and comp−. *Comp−* was the only factor that added to *external regulation*.

Table 4 showed that *overall evaluation*, *enjoyment* and *relevance* were very well predicted by the different motivation types ($R^2 > 0.51$). Next to *intrinsic motivation*, both *amotivation* and *identified regulation* were important to predict *overall evaluation*. Since *enjoyment* as concept was closely linked to *intrinsic motivation*, the strong predictive power of *intrinsic motivation* was not a surprise. Again, *amotivation* was important here. *Identified regulation* was the strongest predictor for *relevance*. We could reproduce the results of Honkala et al. (2015) that Relative Autonomy Index correlates weakly with *Grade* ($R = 0.143$, $p < .001$). Nevertheless, *grade* as well as *rigour* were badly predicted by the motivation factors.

7.2. Strong autonomy and competence polarisation between students

We complemented the quantitative analysis with a thematic analysis of the open questions. We associated the nine course elements with basic needs. Students did not systematically refer to relatedness. Autonomy (Table 5) and competence (Table 6) were clearly mentioned.

The *course set-up* induced *aut−* and *comp−* due to the strict assignment deadlines and the fact that students were assigned to a student-group (and could thus not choose their group-members

Table 2. Stepwise Linear Regressions of basic needs predicted by course elements indicating β, R^2 and *F*.

	Aut+	Rel+	Comp+	Aut−	Rel−	Comp−
Course Set-up			.115*	−0.195***		−.172***
Course Material	.196**	.179***	.125**			
Lectures	.110**		−.116**			
Tutorials		.143**				
Assignment	.142**		.480***			
Final Test						
Interim Test						
Peer Feedback	.113*	.108*				
Tutor Feedback	.146**	.193***	.143***		−.129**	
R^2	0.286	0.236	0.473	0.038	0.017	0.030
F	$F(5, 577) =$ 46.31	$F(5, 580) =$ 44.81	$F(5, 580) =$ 104.23	$F(1, 582) =$ 23.09	$F(1, 583) =$ 9.89	$F(1, 581) =$ 17.78

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Table 3. Stepwise Linear Regressions of motivation types predicted by basic needs indicating β, R^2 and *F*.

	Intrinsic motivation	Identified regulation	Introjected regulation	External regulation	Amotivation
Aut+		.076*	−0.157***		
Rel+					.111**
Comp+	.587***	.549***	.244***	.366***	−0.323***
Aut−			.170***		.177***
Rel−			.093*		.215***
Comp−			.255***	.237***	.183***
R^2	0.344	0.345	0.227	0.175	0.280
F	$F(1, 602) = 316.21$	$F(2, 598) = 157.23$	$F(5, 594) = 35.17$	$F(2, 600) = 63.66$	$F(5, 594) = 46.19$

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Table 4. Stepwise linear regressions of course outcomes predicted by motivation types indicating β, R^2 and *F*.

	Overall Evaluation	Enjoyment	Relevance	Overall Grade
Intrinsic motivation	.497***	.623***	.167**	
Identified regulation	.127**		.398***	
Introjected regulation				
External regulation				
Amotivation	−0.240***	−.224***	−0.286***	−.180***
R^2	0.561	0.589	0.514	0.032
F	$F(3, 605) = 258.18$	$F(2, 606) = 433.47$	$F(3, 600) = 211.29$	$F(1, 602) = 20.11$

**$p < 0.01$.
***$p < 0.001$.

Table 5. Students' open question answers about course elements related to autonomy.

Autonomy
Set-up: 'The deadlines were inflexible and hard to include in your weekly study schedule'. 'Allow students to make their own groups. Seriously. I'm a pretty hard worker (completed the course with a 9) and so are my friends. None of them were satisfied with their group members: random students tend to be okay with a 6. That's extremely frustrating for those people who want to create something that's really good. It lowers the motivation and morale for those who actually care about it'.
Course materials: 'I found the ethics book a little bit disordered and written in an uninteresting manner, but that is just my opinion'.
Lectures:
'I think the lectures gave a great overview of the course material. The most important parts were picked out and treated so everyone knew the main line of thinking and then the book and reader elaborated on these main things'.
Assignment
'Also the assignment in general was a bit vague and at the start it was just really unclear what the purpose was and which subgroup of what group of which subject was meant at what time when mentioned in the assignment or during the tutoring because all these divisions in groups and subgroups made it all very confusing'.
'I mostly liked the freedom in the assignment. We were able to go whatever direction we liked and I liked that'.
Interim test (*quizzes*)
The fact that you can write the assignment in your own time just like the quizzes
Feedback
'We had to give way too much feedback which led to people just writing something to get it done and not using the feedback because it was simply too much of the same'.

themselves). The choice of cases that fit the students' ethical interest, seemed not to have an impact. For many students, the history and ethics *course materials* did not provide structure and decreased their autonomy, even though other students found the materials captivating. It is unclear how first year's engineering students processed the materials and what they needed from a book to get structure in an ethics and history of technology course. The *lectures* were generally valued well-providing structure and autonomy, however, some students found them too easy and therefore tedious. It is clear that differences in the student background played a role in the perception of the course. When *tutorials* were seen as useful, their relatedness aspects were stressed, but many students experienced them as having little use. The tutorials were meant to provide information, self-study

Table 6. Students' open question answers about course elements related to competence.

Competence
Set-up: 'Working together with unknown people from other studies created a chaos for the assignment and the tutors lacked solutions to solve these cooperation problems'.
Course materials: 'Both the history and ethics part of the reader/book have interesting and telling examples out of real-life to illustrate the importance of the subject discussed. This takes the course material up to a far more captivating level'.
Lectures: 'Lectures were way too easy and rambled about very easy subjects way too long'.
Tutorial 'I felt like the lecture part of the tutorials did not add much to these tutorials, they did not provide any new information and only summarised the basic topics that were discussed during the other lectures. This time could be spent better in my opinion'.
Assignment
'The assignment was not really something I learned from, it did not feel like the material and assignment connected that much'.
'The assignment was really helpful in both an educational way as in a professional skills way'.
'The practical work assignment is not that interesting. It's just writing and writing and not that deep. It's really just writing text without that much content'.
'I found the application of the content of this course hard'.
'The assignment was very challenging and motivating for studying ethics and history. This part of the course should definitely stay'.
Final exam 'The final exam of this course felt like primary school history, in that I mean, in order to score sufficiently, you just had to know the books by heart. Please force students to think instead of just learn'.
Interim test (*quizzes*)
The fact that the quizzes were online also helped as I can look at them again when I was studying for the final exam and see what I did wrong before.
Providing students with practice questions might also be a good idea, on top of the questions that appear in the online quizzes (which are graded for the course).
Feedback:
Also, feedback from tutors is great but if we get it the week before the deadline, there is not that much we can do as we have other courses as well.

and practice, but were not experienced as such. Students experienced the tutorials as too complex and not supportive of the basic needs. Knowing how engineering students process history and ethics materials are core for making improvements here.

Many comments referred to the *assignment*. Quite a number of comments focussed on the lack of clarity in the assignment, influencing students' competence, but also their autonomy. Engineering students differed in their opinion whether the ethics and history was enjoyable, interesting, relevant, and whether they learned new things, but students' emphasis was on the negative side. Some indicated that the assignment was really too hard, indicating that it was too complex and it decreased their feeling of competence, whereas some students found it too easy.

The multiple-choice *final exam* was considered problematic by many students, mainly for the focus on reproduction. They referred to the contradiction of, on the one hand, the learning objectives of the ethics and history of technology course to engage students in critical thinking and, on the other hand, the cognitively narrow format of a multiple choice exam. The *interim exams* were online quizzes and the choice when they could be done in the foreseen period was appreciated. Students however strongly reported that the online interim tests were not sufficient to give them the assurance that they were ready for the exam. Because history and ethics are more distant from their 'usual' courses and their comfort zone, they seem to ask for more structure. Students also indicated that communication between teachers, tutors and study guide was sometimes confusing. They also stressed they needed timelier *tutor feedback*. These are general requirements (Hattie and Timperley 2007), but in history and ethics courses, engineering students certainly request sufficient structure and guidance.

These course elements all added up to a moderate *aut*+ and *rel*+, but low *comp*+ and low motivation types. Students had to write about 500 words per student per week. Many students considered this way too much. As the *rigour* question is formulated very openly, students referred mainly to the quantity of the work indicating that this was mainly their concern. Quality was far less mentioned, neither positively nor negatively, which seemed to indicate that this was less of an issue to them.

The quantitative and qualitative results answer both research questions. The course elements could be modelled as input variables, basic needs and motivation as intermediate variables and course output as outcome variables. This analysis provided direction to perform a redesign that is to focus on competence in the assignment. The qualitative analysis added insight in the meaning to the quantitative results.

8. Discussion

The item correlations of the basic needs variables indicated that even after recoding negatively formulated items, autonomy, relatedness and competence still appeared to consist of two subscales each. The poor fit of the three-factor model to the basic needs items confirmed this impression. Based on the results of this analysis, we tested whether the three basic needs categories could be treated as bivalent; a dimension measured by the positively formulated items and one measured by the negatively formulated items. We opted for a six factor model with one negative and one positive factor per basic need. One possible explanation is that our questionnaire – which was composed of items from several validated questionnaires for basic needs, motivation types, et cetera – somehow invoked a spurious answering pattern for the negatively formulated basic needs items. Another explanation could be that engineering students experienced satisfaction of basic needs, but also frustration in this ethics and history of technology course because their needs are actively thwarted. The concept of basic needs frustration got more attention since the beginning of this decade and basic needs questionnaire focussing on both frustration and satisfaction are available (Bartholomew et al. 2011). Vansteenkiste and Ryan (2013) refer to the asymmetry of basic needs because in some cases one can experience a lower satisfaction of some basic needs (deprivation) without them being actively thwarted. Our questionnaire was not validated for measuring basic needs satisfaction and frustration. However, referring to the negatively formulated questions as ‘I felt pressured to do things in a certain way during the course’, we hypothesised that our instrument might have detected and brought up, at least partially, the frustration aspect. If so, we can interpret *aut*− as autonomy frustration, *rel*− as relatedness frustration and *comp*- as competence frustration. We think engineering education in general, and courses on ethics and history of technology in particular, could strongly benefit from Engineering Education Research how students deal with frustration aspects in courses that are not core to engineering students’ interest. Focusing on positive or satisfaction aspects is important, but both research and course redesign should not forget the role of frustration.

The SDT analysis using the Vallerand model allowed some prioritisations for course design. Up and front was the *assignment* that should answer student’s *comp*+, which lead to *intrinsic motivation* and *identified regulation* and an increase in *overall evaluation*, *enjoyment* and *relevance*. The next step in course redesign will be to determine what a course should look like if the aim is to increase students’ *comp*+ . The open questions provided some guidance here. A redesign will first of all require offering a simple structure to students. An assignment with a strong link to the own departments, that refers to a real-life case, which would be recognisable for 1st year students will most likely also increase *comp*+ . However, more research is needed to precisely define what *comp*+ exactly means for the first year’s engineering students enrolled in a history and ethics course.

As an example, our research found out that students interpret *rigour* as ‘quantity of writing’. It also revealed the need for quality of learning as a course outcome. We are interested in how far students intend to understand the meaning of the text or task, try to relate new information to prior knowledge, structure ideas into comprehensible wholes, and critically evaluate knowledge and conclusions they encounter (Marton and Säljö 1976; Zeegers 2001). Further study should inquire how deep and surface learning be integrated in the model (Bombaerts et al. 2018) in order to address *comp* + .

A second priority was to simplify the complex *course set-up*. The boundary conditions made the course already very complex: two disciplines (history and ethics) that are far from the students’ own disciplines, two languages, a limited time frame of nine weeks, 14 departments, multidisciplinary team work, to 1886 first years’ students, executed by more than 30 different instructors. The un-prioritised application of basic needs supportive elements added to this complexity. As a result, the set-up was not clear enough for students and intensified their *aut*− and *comp*−. It probably was too ambitious and put too many things together in a short time of nine weeks. The feedback system is a proper example. Although the system of students giving two individual peer feedbacks and receiving about eight feedbacks for their group in return has shown very good results in other contexts (Bombaerts and Nickel 2017), the time allocated for feedback in this course was too short to give sufficient and qualitative feedback for students. A peer feedback cycle of uploading a first version, giving feedback and implementing the feedback needs time to lead to good coaching (Van Diggelen et al. 2019). In a nine-week course, a maximum of two of these cycles seem really feasible. In conclusion, this course needs a much simpler set-up. Assignments should be simple, communication should be crystal clear and the management structure between all instructors involved should also be clear-cut.

A third priority were the history and ethics *course materials.* Overall, the model showed that they are important to realise *aut*+ and *rel* + . Whereas students were given some basic texts to start with their cases, they were encouraged to look for additional sources of their own. The course should offer materials that are very comprehensible for first year students. The instructors should also try to find out how students use the books and which problems they encounter with all the course materials. A possible preparatory step before reading texts could be online publically available videos on history and ethics topics.

9. Conclusion

Basic needs supportive changes in the redesign of the ethics and history of technology course were carried out without making a prioritisation beforehand. It led to an ambitious, but too complex course which partially supported engineering students, but also did not match well enough basic needs of many others. The first conclusion from this analysis was that an intuitive and un-prioritised SDT-based redesign has no guarantee to realise the intended improvements. Whereas Herman et al. (2017) stress the possibility of a low-cost intrinsic motivation course conversion, we want to add that a successful SDT redesign requires detailed analyses to allow a prioritisation on how to redesign complex courses and avoid unwanted drawbacks. Courses with strict and demanding boundary conditions may have a recurrent bad evaluation, even when many experienced teachers and course redesigners are involved. It is far from self-evident to understand how course redesign affects basic needs and what the best approach is in a basic needs supportive redesign.

However, the use of the Self-Determination Theory, and in our analysis the Vallerand model, enabled to prioritise the redesign of the ethics and history of technology course. *Comp*+ was key in our analysis stressing the importance of the assignment in the course. Although we had a large set of answers to the open questions in our qualitative research, further research is needed to understand what *comp*+ really means for students and how it could be strengthened.

We proposed that basic needs satisfaction and frustration could be important concepts in a further analysis. Other questionnaires are validated to describe these differences and higher Cronbach's alpha's compared to our instrument have been reported (Chen et al. 2015). Being a concept only fairly recently developed and operationalised, the basic needs frustration concept has not been used in EER as far as we are aware and requires further research. We anticipate that such research might be very useful for ethics and history courses in particular and in Engineering Education in general.

Our results concerned one version of one course at one university. Further research could try to replicate the issues discussed here. Can this method provide clear priority for other history and ethics courses as well, or for engineering education in general? Do *external regulation* and *introjected regulation* fail to predict course outcomes also in other contexts or courses? Are *grades* and *rigour* badly predicted by motivation and what could predict them better? And what is the impact of the size of the course on the different results?

We conclude that the Self-Determination Theory in general and the Vallerand model in particular, were a useful tool for prioritising redesign in this course. We suggest further research on the application of SDT and Vallerand's model in course design, on the role and meaning of *competence* and on the role of frustration, in ethics and history courses in particular and engineering courses in general.

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