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A SENIOR SECONDARY SCHOOL PHYSICS CURRICULUM FOR TALENTED STUDENTS

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ABSTRACT
At the Junior College Utrecht, talented students of grade 11 and 12 get an enriched science programme. The JCU curriculum has six specific characteristics, such 'accelerated', 'enriched' and 'JCU-atmosphere'. It appears that students feel empowered by the JCU education. In their perception, their empowerment is influenced by the JCU curriculum characteristics. In this study, we reflect as physics teachers in JCU on our physics curriculum and interpret the empowerment results. We identify what characteristics contribute to students feeling empowered and what characteristics have negative influences. This results in intentions for improving our curriculum and in recommendations for empowering talented students in regular secondary schools.

KEYWORDS
Talented students, senior secondary school, science, physics, empowerment, curriculum characteristics, curriculum innovation, differentiation

INTRODUCTION

Gifted students that are motivated for science and mathematics can become crucial contributors to the future technological society. However, in secondary schools the needs of this group are rarely met. Therefore, in many countries special programmes for talented science students have started including masterclasses (Adamczyk and Willson, 2004), enrichment projects (Taber and Riga 2006) and special science high schools (see e.g. Ngoi and Vondracek 2004). In the Netherlands a specialized *science-enriched* upper secondary school, Junior College Utrecht (JCU) opened its doors in 2004, offering the regular programmes of physics, mathematics, chemistry and biology as well as an enrichment programme (Van der Valk, Eijkelhof and van den Berg 2007). The enrichment is realised within the subjects, e.g. during physics lessons, as well as in interdisciplinary 'modules'.

This paper reports in brief about the results of an investigation into the 'empowerment' of JCU students and the effects of some main JCU curriculum characteristics. Using the results, we as physics teachers reflect the results of the investigation: (how) do our physics lessons contribute to the empowerment of the students? We give some recommendations to regular schools how to empower their talented students in physics lessons.

THE CONTEXT: JUNIOR COLLEGE UTRECHT

In 2004, Utrecht University initiated Junior College Utrecht in cooperation with secondary schools from the Utrecht region. It has an approach that is unique in its institutional, educational, curriculum and outreach aspects. Students as well as partner schools should benefit from the JCU. It therefore has a dual purpose:

- to offer interesting and challenging science education to talented students (grade 11 and 12)
- a working place for innovation of the science and maths curriculum to partner schools

26 Schools have joined the network to provide their talented students with sufficient challenge. They are also interested in the science education laboratory function and in closer contacts with universities, as they recognise that not only students, but also teachers and schools benefit from exchange programmes with a university (Luehmann and Markowitz, 2007).
JCU students have to fulfil the requirements of the regular Dutch pre-university stream curriculum (Dutch acronym VWO), which is typically taken by 20% of the population of 16 -18 year olds. For details of the Dutch School system see website at the end of this article. Dutch VWO students sit examinations in a variety of subjects. JCU-student take all four subjects physics, chemistry, biology and mathematics.

JCU-students are carefully selected. In the partner schools, grade 10 students who want to apply for JCU, can indicate their interest to the staff of their school. Every partner school is allowed to nominate up to four candidates, so a first selection is made at school. The JCU-selection committee conducts interviews with all nominated candidates and makes the final selection. It is based on academic potential, general ability in autonomous learning, motivation, and the desire to get a varied group in terms of student interests, boy-girl balance, and representation from different partner schools.

On Monday and Tuesday the students have their lessons at JCU. The other days of the week they are in their regular schools studying non-science subjects as well as doing JCU-assignments. Having completed the JCU, 80% of the students (N=120) have entered a science or technical study in university, 25% of which opted for physics or related technical studies.

JCU employs teachers from partner schools to teach the secondary school science. For the regular VWO science syllabuses, the JCU uses textbooks that also are used in regular schools. University lecturers from the Faculty of Science of Utrecht University are involved in teaching enrichment modules. To develop and implement the enrichment programme, JCU has a staff of professional developers headed by the curriculum coordinator that cooperates with teachers from secondary schools and scientists from university.

Due to a curriculum reform, in 2007 a new subject was introduced in senior secondary school: Advanced Science (or, literally translated, it is named: *Nature Life and Technology, NLT*). It turned out that the modules from the JCU enrichment programme (see Table 1) fit into this innovative programme.

Table 1. The JCU enrichment programme. In grade 12, two modules are taught in parallel so that the students can choose.

	The JCU advanced science modules	
Grade 11	Purification of drinking water	
	Dynamic modelling	
	Molecules in Life	
	Looking and Seeing	
	The Quantum Structure of Matter	
Grade 12	Complex circuitry	The Moving Earth
	Nanoscience	Lifecycle of stars
	HIV/AIDS	Ice and Climate
	Diophantic equations	Heart and veins

The JCU curriculum has six main characteristics that are present in the curriculum as a whole as well as in the curricula of the four subjects, like in the physics curriculum. These are:

- *accelerated curriculum*. The national science syllabuses are taught in 60 – 70% of the time allocated in regular schools.

- *enriched programme*: the curriculum includes topics that go beyond the syllabi. For a main part, it is in the form of modules about modern and interdisciplinary topics (see Table 1)
- *research-oriented*: much lesson time is spent doing lab work in university laboratory facilities. Moreover, students conduct two major investigation assignments ('pre-thesis' and 'JCU-thesis').
- *similarly disposed peers*. Students are selected from the JCU partner schools regarding their interest and motivation for the sciences; they meet their equals in JCU.
- *approach of teachers*. The teachers aim at an approach that is tuned to the specific interests and capacities of the JCU students.
- *JCU atmosphere*: at the JCU, teachers and students socialize informally during the classes as well as by social activities; initiatives and participation in additional activities (seminars, Olympiads) are appreciated.

EMPOWERMENT OF JCU STUDENTS

In this section we introduce ´empowerment´ and summarise the results of an investigation of Van der Valk *et al.* (2008) to the empowerment of JCU students and the effect of the JCU curriculum characteristics on it.

As teachers, we have experienced that the students grow significantly in their interest in science and in their working attitude during JCU education. To describe this growth, the concept of empowerment (Luechauer and Shulman, 2002) has been useful. They define educational empowerment as "the dynamic process of adopting the values and enacting the practices of enlightened self-interest in order to align students and faculty [= teachers and principals] goals for the class". Alignment occurs when students and faculty share the authority and responsibility to devise the processes and measures necessary to facilitate learning. By empowering, JCU wants to make its students feel significant, excited and challenged by studying science at JCU. Their contributions to the lessons should really matter, they should feel like a member of the JCU community, their feelings of self-esteem, self-efficacy and motivation for science should increase, they should be willing to take initiatives and risks, e.g. by partaking in the Physics Olympiad, by contacting scientists from university and asking them to participate in seminars.

Thomas and Velthouse (1990) outlined four components of educational empowerment: impact, choice, meaningfulness and competence. Shulman, Houser and Frymier (1995) found that impact and choice form one factor. We have adapted the description of the components to the JCU context:

- meaningfulness refers to the values of JCU-tasks in relation to students' own beliefs and standards
- competence: the student feels qualified and capable to perform the necessary activities to accomplish the JCU tasks and to reach the learning goals
- impact: the degree to which students perceive that their contributions to the lessons really matter and to which students self-determine task goals and methods to accomplish them.

Van der Valk *et al.* (2008) have measured the empowerment and its components with 75 JCU students using a questionnaire with 26 5-point Likert scale items. The questionnaire had a sufficient reliability (alpha = 0.86). The three component subscales impact, meaningfulness and competence were also sufficient reliable (alpha between 0.73 and 0.89).

Results (Table 2) showed that the JCU students felt empowered. There were no significant differences between the grade 11 and 12 groups and between boys and girls. Neither, there were significant differences between the three components of empowerment. However, for the component 'competence' there is a significant difference ($p < 0.05$) between boys and girls. This difference could not be attributed to differences in learning results, for although the girls' mean science and mathematics marks were a bit lower, the difference with the boys' mean marks was not significant.

Table 2. Empowerment of students (1= no empowerment. 5= high empowerment); s.d. = standard deviation.

	Complete group (N=75)		***Grade 11 (n = 38)***		***Grade 12 (n = 37)***		***Boys (n = 44)***		***Girls (n = 31)***	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Empowerment	3.85	0.40	3.86	0.48	0.85	0.31	3.91	0.42	3.77	0.38
Impact	3.70	0.51	3.70	0.54	3.71	0.49	3.72	0.52	3.69	0.51
Meaningfulness	3.88	0.51	3.98	0.58	3.77	0.42	3.84	0.57	3.93	0.43
Competence	3.91	0.62	3.83	0.71	4.02	0.43	4.11	0.46	3.62	0.70

Van der Valk *at al*. also measured students' perception of the effect of the six JCU curriculum characteristics on their empowerment. It appeared (see Table 3) that, in the students' perception, all characteristics had a positive effect on empowerment. 'JCU atmosphere' had the most effect and 'accelerated curriculum' had the least effect.

Table 3

JCU-characteristics	***Mean influence of JCU characteristic on empowerment***
accelerated curriculum	3.46
similarly disposed peers	3.60
research oriented	3.68
approach by JCU teachers	3.70
enrichment	3.77
JCU atmosphere	4.05

With respect to the components of empowerment, it appeared that 'meaningfulness' was significantly more influenced and the impact component less influenced by the joint six JCU characteristics, compared to the mean score ($p<0.01$). There were no significant differences between boys and girls or between classes.

INFLUENCE OF THE PHYSICS CURRICULUM ON EMPOWERMENT

In this section, we reflect on our physics curriculum, using the results reported in section 3, by answering the question: *How do the six JCU curriculum characteristics, as implemented in the physics curriculum, influence students' empowerment?* We use some student statements taken from open-answer questions in the evaluation questionnaire administered at the end of the school course 2007/08 in both the grade 11 and grade 12 classes.

Accelerated curriculum

In JCU, subject matter from the national pre-university syllabus is taught in an accelerated pace, in 60% of the time allocated in regular schools. All JCU-students agree that acceleration is needed for getting challenged and for making room for enrichment and they are motivated for the sciences indeed. But in our classes we meet, roughly spoken a group of mathematical/technical oriented students and a life-science oriented group. The former always likes to go deeper into comprehensive and fundamental physics questions, the latter want to take more time for the basics of physics they need for the life sciences. They have problems with acceleration in physics: *It goes too fast. Physics is really difficult and the theory cannot be understood rapidly in this way.* To them there is too little time to digest subject matter. They get unsure and their self-confidence may get damaged. Occasionally, we organise additional opportunities to ask questions. Moreover, they can use an electronic learning environment for asking questions when they are in their schools or at home. But it appears that it is not enough: they want a lower acceleration rate.

So acceleration in our physics lessons has an advantage (supplying room for enrichment) as well as a disadvantage (shortage of time to some students needing a lower pace for understanding the basics of the physics curriculum). The latter may explain why the accelerated curriculum characteristic adds relatively little to the empowerment of the students.

Similarly disposed peers

The students that are admitted to JCU are selected on their talents and their motivation for science and mathematics. It affirms them in their competence. They meet peers with same interests and capabilities and like it very much. In the words of a student: *JCU has brought me in contact with peers who are equally passionate as I am.*

In our physics lessons, working with people with a passion for science is stimulating for us as well for the students. We experience that small group work e.g. in the physics lab runs well as all students are cooperative and feel accountable for the learning process and results. In regular schools, talented students sometimes complain that they can do the hard work and their less talented peers only profit from their efforts.

The 'similarly disposed peers' characteristic, however, also has some aspects that do not contribute to empowerment of students. One of them appears in the following quote of a JCU-student: *It was now and then frustrating that I was not automatically the best of the class anymore if I did my best. In the beginning of JCU, it even was demotivating.* We experience the effects of students having high expectations of themselves in the classroom. Students hesitate to ask for more explanation if they have the impression that 'everybody' does understand but they don't. Then, they take their questions home and try to find an answer autonomously. That costs them a lot of work and gives them stress, in particular if they can't find a solution and get lower marks than they are used to. It may be harder to girls than to boys to rest in not understanding for a while, without loosing self-confidence. That may explain the difference between boys and girls in the competence component Van der Valk *et al.* (2008) have found.

Research oriented

The JCU curriculum is research oriented by three ways: in using university labs, in having students do investigations and in bringing them in contact with scientists and recent scientific work. In physics lessons, we spend about one quarter of the lesson time to lab work in university laboratory facilities. By this, students get an impression of the atmosphere and ways of working in the physics department of our university. During lab work, lab skills are trained and experiments are done. As the course proceeds, the experiments get a more open character. This attaches to a main factor in empowering students and developing their talents: to give them room for posing and attaining their own aims.

The students do two large research assignments: the prethesis (40 hours of work) and the thesis (120 hours of work). About a quarter of the students chose a physics related topic for their research. They are guided by physicists and work as guests in a physics research groups. Sometimes they are allowed to use advanced equipment. To many students, doing the thesis is the top happening of their JCU time. A student wrote as an evaluation of the thesis: *We really learnt how to set-up an experimental study, how to conduct it and how to write a report. Our coaches from the university were very enthusiastic and helped us well.* In fact, many students want to do more research and open experiments, for then they can work on issues they have chosen themselves. Not only in the (pre)thesis, but also in the JCU enrichment programme, students meet scientists teaching modules such as Looking and Seeing (the visual system) or Complex Circuitry (describing alternating current with complex numbers). Moreover, Every year JCU has an excursion to CERN in Geneva. The students enjoy seeing the huge experiments and: b*y visiting CERN I got more interested in physics theory.*

So, the research context oriented characteristic is surely present in the physics curriculum and contributes to students' empowerment.

Approach by JCU teachers

In JCU, teachers take an approach that is geared to the needs and opportunities talented students have. In our physics lessons we use the idea of compacting and enriching (Reis and Renzulli, 1992). Using Powerpoint presentations, we present physics topics in large integrated pieces which contain the essentials of a particular topic. This is contrary to the approach in regular classrooms where topics are broken down into small pieces. Our approach has the advantage of students' understanding starting from an overview. They know the large framework in which details are important. It facilitates the acceleration and stimulates better understanding. Our students recognise and value this approach, as appears from a statement of a student about the approach in physics: *many examples, good ppt-presentations, the essence of the subject matter topic is presented well and there is no redundant information.* Students meet the details when they read the textbook. Working on a set of essential exercises on a topic, they digest and experience whether or not they understand subject matter. If they need to exercise more, they can choose from a set of additional tasks. However, students complain that they do not have enough time to do the additional exercises. In direct interaction with the teacher, pupils check their understanding: o*ften, we are challenged to think with small examples and experiments that are demonstrated. That makes the theory clearer to me.* Moreover, a part of the lesson time is dedicated to discussing issues suggested by the students. Students recognise it: *in physics lessons, there is much room for discussion about more fundamental topics.*

So, we feel that our approach in the physics lessons promotes empowerment. We feel that our approach can be improved e.g. by asking students to read a chapter before dealing with it in the classroom.

Enrichment

The time saved by acceleration is used for enrichment of the curriculum, in three ways. The first way is going beyond the syllabus in subject lessons. In physics lessons, we pay more attention to backgrounds, to formal aspects of the theory and to lab work than we do in the lessons in our regular schools. We exploit the opportunities for going deeper into subject matter that are provided by students' questions. Moreover, we participate in the Modern Physics project (Hoekzema, Schooten, van den Berg and Lijnse, 2005), introducing students, among others, in the non-formal basics of quantum mechanics. The second way is by extra activities like the excursion to CERN or a project with mathematics on GPS (Global Positioning System). The third way is the enrichment programme with interdisciplinary modules. Quite a few of the modules have a strong physics component, e.g. 'Ice and Climate', 'Complex Currents' and 'Life Cycle of Stars'. Some students found that there is too much physics in the modules (*many modules were too much focused on physics while I know that many students like biology and chemistry better*), however other students complained that *there were too few challenges related to physics and mathematics*. Here the difference between life science- and physics/mathematics oriented students catch the eye again.

Although not all students like all physics parts of the enrichment in the JCU-curriculum, physics enrichment surely adds to empowerment by enrichment, and by giving students backgrounds of formal physics.

The JCU atmosphere

The JCU atmosphere is determined by the informal meeting of students and teachers and by the whole of social and content activities. The students like the atmosphere at JCU very much, e.g.: *JCU is simply fantastic. A nice challenge, a nice atmosphere and much freedom of choice*. Besides 'freedom', experiencing mutual respect is a characteristic of the JCU atmosphere to students: e*verybody is treated equally, with respect. Students are listened to*. A third aspect is being stimulated to develop the best out of oneself. In the evaluation, many students refer to an increase of their personal competence. E.g. *I have learnt to work much more efficiently and now I have a much higher level of thinking than I would have had without JCU.*

The feature related to the atmosphere in the physics classes the students mention the most is the enthusiasm for physics we as teachers show in our lessons. *That has made me enthusiast for physics. It has stimulated me to develop my way of learning.*

So the JCU atmosphere and the atmosphere in our physics classed have surely contributed to students' empowerment for science in general and for physics in particular.

CONCLUSION, DISCUSSION AND RECOMMENDATIONS

In this study we have investigated how the six JCU curriculum characteristics, in particular the way they are implemented in the physics curriculum, influence students' empowerment. In this, we attach to Van der Valk *et al.* (2008) who found, in general, that JCU students feel empowered by all six JCU characteristics and that the empowerment is influenced the most by 'JCU atmosphere', the least by 'accelerated curriculum' and 'similarly disposed peers' and intermediate by 'enrichment', 'approach by JCU teachers' and 'research oriented'. We relate our results to the three dimensions of empowerment: meaningfulness, competence and impact.
With respect to the 'JCU atmosphere', we have found that this JCU curriculum characteristic influences students' empowerment by giving the students a general feeling of being engaged in meaningful learning activities, of developing their competences and by students having impact: treating them with respect and giving them influence on goal and activities. The physics curriculum adds to the atmosphere by the enthusiasm the physics teachers show and by giving opportunities to discuss on comprehensive physics issues students bring in.

The 'enrichment' characteristic influences students' empowerment by supplying them with meaningful subject matter that goes beyond the syllabuses and by supporting students' competence to deal with these topics. The physics curriculum adds to that in that it includes much enrichment subject matter. However, students would like to have more chances for choosing or not choosing physics related modules in the enrichment programme (impact).

The 'approach by JCU teachers' characteristic has an effect on students' empowerment in that students feel affirmed in their competence and they can have an influence on what they do and learn. The physics teachers' approach of starting with an overview adds to this in that it is geared to the needs of talented students. However, in particular in physics lessons, students would like to have more options in adapting the pace and the number of exercises to their own needs and understanding.

The 'research oriented' characteristic achieves that students feel empowered in their competence to do research and in setting their own goals when designing and carrying out a research. Moreover, by getting a view on university science, they get meaningful information that may help them in orienting on the choice of their future study. The physics curriculum adds on that, among others, by making the experiments more open during the course. The students, however, expressed that they would like to do still more open tasks and investigations.

The 'similar disposed peers' contributes to students' empowerment in that students find it meaningful to share ideas with peers with an equal passion for science as they have. They experience more mutual understanding by their JCU peers than by their fellow students at school. However, to some students the confidence in their competences is undermined by not being the best of the class anymore and by attaining lower marks. In particular this is the case for physics.

At last, the accelerated curriculum' characteristic adds to students' empowerment by making room for teaching meaningful topics that go beyond the syllabus and by affirming that the JCU students are able to understand the syllabus topics in a shorter time than their peers in the regular school. However, in particular in physics, some students find the pace too high, what disadvantages their understanding and afflicts their feeling of being competent. They want to have more time for the basics of physics.

Interpreting these results, we see that nearly all characteristics have a positive influence on the meaningfulness component of students' empowerment. The 'accelerated curriculum' and 'similarly disposed peers' characteristics have positive and negative effects on the competence component of empowerment. That explains that the joint characteristics have more influence on meaningfulness than on competence. However, the influence on the impact component is the smallest one. That can not be explained by our results as we did not find negative influences of the characteristics on the impact component. We just found that students would like to have more impact on the curriculum by having more open assignments, getting more opportunities to make choices and to do research. So it seems that the empowerment can be enlarged by paying more attention to the impact component of empowerment.

Intentions for our future physics lessons

Using the results of this study, we intend to modify the physics curriculum on some points. A part of our students have problems with the high pace in the physics lessons. They need more time for asking questions and getting additional explanations and tasks. However, the other part of the student is quite happy with the actual pace. So we need to meet the differences between students. Some students must get more time for digestion of subject matter; others want more open comprehensive assignments. Happily, from the 2008/09 course on, the physics, chemistry and mathematics syllabi are diminished and this gives us better opportunities to meet the students' needs. JCU is going to construct some differentiated tasks for physics (as well as for the other subjects) and include differentiation structurally in the curriculum. The differential 'basic tasks' are designed for students who want to understand the physics syllabus topics. The differential 'comprehensive tasks' should be suitable for students and deal with topics that go beyond the syllabuses. By more options for students and more open assignments, we also meet the need for re-enforcing the impact component of empowerment, by letting students choose between modules, using more student contributions and the like.

Recommendations for regular schools

Many regular schools for pre-university education have talented students that are not challenged enough. They can profit of the ways for giving students more challenge that have been tried out by JCU. To empower their talented and less talented students for physics, they, in the first place, should create an atmosphere in the school in which doing science is 'cool' and studying topics beyond the syllabuses is valued by teachers and fellow students. For this, they have to develop a curriculum that gives students, after having studied the basics of a physics topic, different options: more digestion or enrichment. As a means for this, regular schools can start explanations of the basics of a physics topic with presenting an overview with the essentials of the topic, before explaining the details, instead of the traditional approach of starting with details. That approach gives possibilities for acceleration to the more talented students. Next, differentiated tasks should provide opportunities for more digestion or enrichment. As a closure of a differential period, talented peers can present their results of their enrichment tasks to the fellow students. The less talented students can present their explanations of syllabus subject matter. For realising this new approach, JCU lesson materials for physics and other science subjects will be made accessible for all Dutch schools.

REFERENCES

Adamczyk, P., and Willson, M. (2004). Promoting learning out-of-school: the master class experience. School Science Review, 85(313), 55 – 60.

Hoekzema, D.J., Schooten, G.J., Berg, E. van den, and Lijnse, P.L. (2005). Conservation laws, symmeteries, and elementary particles. The Physics Teacher, 43(5), 266-271.

Ngoi, M. and Vondracek, M. (1997). Working With Gifted Science Students in a Public High School Environment: One School's Approach. *Journal of Secondary Gifted Education*, 15 (4), 141-147.

Luechauer, D.L., and Shulman, G.M. (2002). Creating empowered learners: a decade trying to practice what we teach. Organization Development Journal 20(3), 42 – 51.

Luehmann, A.L., and Markowitz, D. (2007). Science Teachers' Perceived Benefits of an Out-of-school Enrichment Programme: Identity needs and university affordances. International Journal of Science Education, 29(6), 1133 – 1161.

Reis, S. and Renzulli, J. (1992). Using Curriculum Compacting to Challenge the Above-Average. In: Educational Leadership 50(2), 51 – 57.

Shulman, G.M., Houser, M., and Frymier, A.B. (1995). Assessment of the learner empowerment measure. Paper presented at the Annual Meeting of the Speech Communication Association (San Antonio, Texas 1995) (33p.).

Taber, K.S., and Riga, F. (2006) Lessons from the ASCEND project: able pupils' responses to an enrichment programme exploring the nature of science. School Science Review, 87(321), 97-106.

Thomas, K., and Velthouse, B. (1990). Cognitive elements of empowerment: an "interpretive" model of task motivation. Academy of Management Review, 15, 666-681.

Valk, T. van der, Berg, E. van den, and Eijkelhof, H. (2007). Junior College Utrecht: Challenging talented secondary school students to study science. School Science Review, 88(325), 63-71.

Valk, T. van der, Sissingh Meijer, Q., Pilot, A., and Grunefeld, H. (2008). *Invloed van curriculum kenmerken op empowerment bij getalenteerde bètaleerlingen*. (Influence of curriculum characteristics on empowerment with talented science students). Paper to the 2008 ORD conference, Eindhoven, Netherlands.

Websites
Junior College Utrecht (in Dutch) www.jcu.uu.nl
Information about the Dutch school system: http://www.minocw.nl/documenten/eurydice_en.pdf