# Artificial Intelligence academic programmes in the Netherlands

## A state of the art report

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# Artificial Intelligence Academic Programmes in the Netherlands

## Executive Summary

This report is written as the concluding document of the education assessment Artificial Intelligence, and aims to stimulate the further improvement of AI programmes at Dutch universities. The committee found that each of the programmes it assessed is of high quality. Also, the committee found that programmes are developing constantly and rapidly, in order to keep up with the pace of developments within AI as an academic discipline and with changing expectations of universities and of the Dutch Ministry of Education, Culture and Science.

For a number of reasons the committee has focused its recommendations for further improvement of the AI programmes on the joint (KION) domain specific framework of reference. First, given the pace of change in AI, the KION framework has rapidly become outdated. In order to help updating and broadening the framework's international perspective, the committee has surveyed AI journals, conferences, and textbooks. Second, the committee holds the conviction that the key to further improvement in individual AI programmes can be found in national cooperation. It has interpreted the KION document instrumentally, as a platform for regular exchange of the most recent insights on AI, didactics and educational techniques. National coordination will also help in benchmarking the different AI programmes, increasing their attractiveness both nationally and internationally, and in achieving the KION framework's stated ambition to be a starting point for setting international standards for AI programmes. Cooperation would also bring opportunities for (national) collaboration in courses and curricula, for example in MOOCs. Third, the committee thinks that an up-to-date (and regularly updated) KION document would be a valuable tool to guarantee the quality and topicality of each of the individual AI programmes, both in internal and external assessments. This in turn would help students who hold a Dutch bachelor degree in AI to switch smoothly to any Dutch AI master programme.

Based on its findings during the assessment of the individual programmes, its study of the KION document and an (international) orientation on trends and developments in AI research and education, the committee makes the following recommendations:

- Add several missing topics to the common core for bachelor programmes, both in AI (e.g. search, planning and scheduling, and decision making;) and in supporting disciplines (e.g. information theory, communications theory, graph theory; network science programming languages and platforms for AI; ethical and societal issues relating to AI);
- Give operational specifications of the topics mentioned (definitions, intended learning outcomes, and recommended ECs);
- The current general educational guidelines should be translated into operational guidelines with regard to possible didactic and educational models and their translation into the curricula;
- Rethink the current guidelines for master programmes. Either choose more detailed guidelines to create more uniform, recognizable AI programmes, or allow for differentiation based on a minimal definition of the AI character. This definition should at least include models of cognitive processing and/or implementations of these models;

- Require bachelor and master theses to show how their topic falls within the definition of AI;
- MOOCs can be a valuable tool to ensure a proper coverage of the (updated) common core for the bachelor programmes, as well as an instrument to stimulate national collaboration and international visibility;
- The common core in bachelor programmes should not just be a list of topics offered within the programmes, but should be a common basis for each individual student. Students should at least be enabled to select this core programme;
- The KION framework of reference can only function as a platform for regular exchange of the what-how aspects of lecturing AI if it is sustained be an active network of AI lecturers/programme directors which regularly meets for discussion;
- This network could be further supported by a newsletter about the what-how aspects of lecturing AI, and by a special session at the yearly BNAIC (Benelux Conference on Artificial Intelligence).

# Preface

In 2013 eighteen Artificial Intelligence programmes at six Dutch universities were visited by a specially appointed external Education Assessment Committee. The committee's task was to evaluate whether the quality of the programmes was satisfactory for re-accreditation. The committee was pleased to find that each individual programme lived up to or even surpassed the official quality standards. The committee was also asked by the participating universities to write a state of the art report, providing general recommendations for further improvement of Dutch academic education in Artificial Intelligence. You are currently reading the resulting document.

The aim of this report is to evaluate the state of the art in bachelor and master programmes in the Netherlands in the area of AI so as to stimulate further improvement in academic education in this area.

As the accreditation process has been finished and as the committee has already provided programme-specific recommendations to each of the universities involved, this report will not comment on the quality of individual programmes or compare programmes with each other. Rather, it will provide recommendations for further improvement and formulate suggestions on implementing current and future developments in the programmes. It does so mainly by providing suggestions on how to update and improve the domain-specific framework of reference. This in turn will help programmes to re-examine their intended learning outcomes and curricula accordingly.

The committee would like to thank the universities involved for providing us with the opportunity to write this report. We also thank the Faculties and all people involved for proofreading this document. We hope that this report will help them to further improve the quality of their AI programmes and to prepare them for the next assessment.

On behalf of the Assessment Committee,

Prof. dr. Tim Grant
Prof. drs. dr. Leon Rothkrantz

# 1. Introduction

*In this introductory section, we describe the background leading up to this state of the art report, its purpose and scope, our approach, our methodology, and the report's structure.*

## 1.1 Background

Under European regulations, accredited bachelor and master programmes must be evaluated every six years. Evaluation is based on a discipline-specific frame of reference, and involves the following steps:

1. The university organizers of each programme prepare a self-evaluation report, covering a set of quality standards as defined by the Nederlands-Vlaamse Accreditatieorganisatie[1] (NVAO).
2. A committee of experts reviews the self-evaluation report, visits the university to obtain answers to questions arising from the review, and prepares an evaluation report for NVAO, which then decides on re-accreditation on behalf of the Ministry of Education.

At request of the universities, an organization such as Quality Assurance Netherlands Universities (QANU) oversees the evaluation process. They invite the committee of experts, organize their visits, author the evaluation reports from the experts' inputs, and submit the respective reports to the university boards. The university boards then incorporate the reports in their submissions to the NVAO for extension of their accreditation for a further six years.

With the existing accreditation of the Artificial Intelligence (AI) programmes at six Dutch universities due to expire at the end of 2014, QANU was contracted by the universities in 2013 to initiate the evaluation process. The January 16th, 2013 version of the Kunstmatige Intelligentie Opleidingen Nederland[2] (KION) document entitled "Bachelor and Master programmes in Artificial Intelligence: The Dutch perspective" was used as the AI-specific frame of reference for the evaluation. While the universities prepared their self-evaluation reports, a committee of experts in AI was formed. Appendix B provides an overview of the committee members. During the course of 2013, the committee visited the following universities:

- University of Groningen (RUG). RUG's Faculty of Mathematics and Natural Sciences offers a bachelor in Artificial Intelligence, and two master programmes, one in AI and the other in Human-Machine Communication. The bachelor programme focuses on AI and cognitive science. The master in AI offers the tracks Computational Intelligence & Robotics, and Multi-Agent Systems. The master in Human-Machine Communication is strongly geared towards cognitive science, offering four tracks: Cognitive Modelling, Cognitive Engineering, Computational Cognitive Neuroscience and Cognitive Language Modelling.
- Utrecht University (UU). UU's Faculty of Humanities offers a bachelor programme in Artificial Intelligence, while its master programme is offered by the Faculty of Science. Both programmes offer students a relatively large amount of freedom to choose courses according to their own interests. Furthermore, both programmes have a multidisciplinary profile, oriented toward human sciences ['mensgericht']. The bachelor emphasises

1 Accreditation Organization of the Netherlands and Flanders.
2 Authors' translation: AI education programmes in the Netherlands.

philosophical and methodological foundations, while the master combines a focus on philosophy with an emphasis on designing technical applications.

- Radboud University Nijmegen (RU). RU offers a bachelor and a master in Artificial Intelligence, hosted by the Faculty of Social Sciences. Both programmes focus on brain and cognition. The bachelor adopts active learning as its didactic model. The master builds on this didactic model with the concept of 'active autonomy'. The programme consists of three specializations: Web and Language Interaction, Robot Cognition, and Computation in Neural and Artificial Systems, all three focusing on different areas of natural and artificial intelligence and their interaction..
- Maastricht University (UM). UM offers a bachelor programme in Knowledge Engineering, based at the Faculty of Humanities and Sciences. The bachelor has a strong focus on applied mathematics and computer science. Within the Transnational University Limburg (a joint venture of UM and Hasselt University, Belgium), it offers two master programmes: Artificial Intelligence and Operations Research. The master in AI focuses on games and agents and on knowledge discovery and learning. The master in Operations Research covers classical operations research and systems and control theory as its main themes. All three programmes use Project-Centred Learning as their didactic model.
- University of Amsterdam (UvA). The Faculty of Science at UvA offers a bachelor and a master programme in Artificial Intelligence. The bachelor combines a fundamental, technical profile – focusing on applied mathematics, programming languages, and software tools – with a broad approach, including the linguistic and cognitive aspects of AI. The programme's educational principles are 'learning by doing' and 'active learning'. The master programme has a technical approach to AI, with the emphasis on developing, understanding, and applying computational processes. It consists of five tracks: Gaming, Intelligent Systems, Learning Systems, Natural Language Processing & Learning, and Web Information Processing.
- VU University Amsterdam (VU). The VU's Faculty of Sciences offers two programmes in the field of AI: a bachelor programme in Lifestyle Informatics and a master programme in AI. The bachelor focuses on intelligent applications that support human functioning and wellbeing. The master programme is practical in its focus on AI, while being embedded within a broad scientific, philosophic and social context. The programme offers four specialisations: Intelligent Systems Design, Web Science, Human Ambience and Cognitive Science.

The individual evaluation reports for each of these programmes have been completed and submitted to NVAO. This resulted in a positive advice to extend the accreditation of the six bachelor and eight masters programmes by the Ministry of Education for a further six years.

To finalize the evaluation process, the universities contracted QANU to ask the committee of experts to prepare a further report describing the state of the art in the Artificial Intelligence programmes. This would enable the programmes to be positioned within the global scientific context and to look ahead to future developments in preparation for the next evaluation round. The document you are reading is the resulting State of the Art report.

## 1.2 Purpose and scope

The purpose of this report is to evaluate the state of the art in bachelor and master programmes in the Netherlands in the area of AI so as to stimulate further improvement in academic education in this area.

Since the six bachelors and eight masters have already been evaluated individually, discussing the strengths and weaknesses of individual programmes is outside the scope of this report, as is comparing one programme with another. Instead, the report focuses on what is common to AI programmes in the Netherlands. As well as looking at the set of Dutch AI programmes as a whole, we also review the KION frame of reference on which the re-accreditation was based. We have done so for a number of reasons. First, given the pace of change in AI, the KION framework has rapidly become outdated. In order to help updating and broadening the framework's international perspective, the committee has surveyed AI journals, conferences, and textbooks. Second, we believe that the key to further improvement in individual AI programmes can be found in national cooperation. We have interpreted the KION document instrumentally, as a platform for regular exchange of the most recent insights on AI, didactics and educational techniques. National coordination will also help in benchmarking the different AI programmes, increasing their attractiveness both nationally and internationally, and in achieving the KION framework's stated ambition to be a starting point for setting international standards for AI programmes. Cooperation would also bring opportunities for (national) collaboration in courses and curricula, for example in MOOCs. Third, we think that an up-to-date (and regularly updated) KION document would be a valuable tool to guarantee the quality and topicality of each of the individual AI programmes, both in internal and external assessments. This in turn would help students who hold a Dutch bachelor degree in AI to switch smoothly to any Dutch AI master programme.

There are also other AI courses and specializations in the Netherlands that were not covered by the 2013 evaluation process, e.g. at the three technical universities in Delft, Eindhoven, and Twente. Although these courses and specializations are outside the scope both of the evaluation and of this report, they will benefit from refining the KION frame of reference as a result of the recommendations made in this report.

## 1.3 Approach

Our approach is principled. We pose two questions: what (i.e. the AI content) and how (i.e. the educational process). More formally, we define our top-level research questions (RQs) as follows:

- RQ 1 (the "what" question): To what extent does the KION frame of reference reflect the international consensus on the definition of and the topics covered by the field of AI?
- RQ 2 (the "how" question): How well do the Dutch bachelor and master programmes on AI, considered as a whole, make use of the KION frame of reference and of the latest insights into educational vision, curriculum design, didactic methods, and the professionalization of lecturers?

Both RQs are sub-divided into more specific sub-questions. The RQ 1 sub-questions are as follows:

- RQ 1.0: What is the international consensus on the definition of AI?
- RQ 1.1: What is the international consensus on the sub-fields/topics within AI?
- RQ 1.2: What is the relationship between AI and the wider fields of computer science and cognitive science, together with their reference disciplines?
- RQ 1.3: Does the KION definition of AI reflect the international consensus on the definition of AI?

- RQ 1.4: Does KION identify a set of topics for AI bachelor and master programmes that is compatible with the international consensus on the sub-fields/topics for AI study and research?

- RQ 1.5: Does the KION frame of reference detail the content of the AI topics, e.g. in the form of learning outcomes?

- RQ 1.6: Does the KION frame of reference give any guidelines on educational aspects, such as the educational vision, curriculum design, didactic methods, and/or the professionalization of lecturers specific to AI bachelor and master programmes?

The RQ 2 sub-questions are as follows:

- RQ 2.0: What are the latest insights into educational vision, curriculum design, didactic methods, and/or the professionalization of lecturers at bachelor and master levels?

- RQ 2.1: To what extent are the KION's core and elective AI topics covered by one or more of the Dutch bachelor and master programmes?

- RQ 2.2: How well do the Dutch bachelor and master programmes on AI design their curriculum in a uniform way?

- RQ 2.3: How well do the Dutch bachelor and master programmes on AI define, implement, and evaluate their educational vision in comparison with international best practices?

- RQ 2.4: How well do the Dutch bachelor and master programmes on AI determine the appropriate didactic methods for AI subjects consistent with their educational vision?

- RQ 2.5: How well do the Dutch bachelor and master programmes on AI ensure the continuing professionalization of their lecturers consistent with their didactic methods?

- RQ 2.6: How well do the Dutch bachelor and master programmes on AI organize their teaching and learning processes?

## 1.4 Methodology

The methodology we adopted in preparing this report varied according to the focus of our evaluation. One subset of the research questions focuses on the KION frame of reference, as shown in Figure 1. A second subset centres on the set of Dutch AI programmes, as shown in Figure 2.

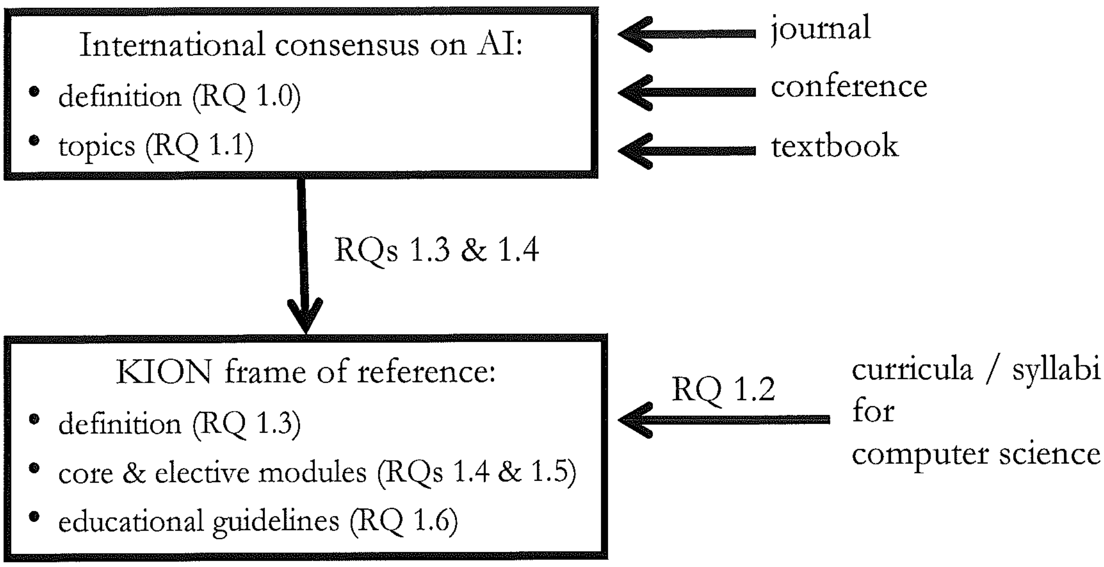


**Figure 1. RQs focusing on KION frame of reference.**

Our review of the KION frame of reference involved four steps (see Figure 1):

1. The first step was to identify whether there was an international consensus on the definition of AI (RQ 1.0) and on AI topics (RQ 1.1), and, if so, to characterize this consensus.
2. The second step was to identify whether there were generic curriculum or syllabus guidelines for computer science and for cognitive science, and, if so, whether the KION frame of reference complied with them (RQ 1.2).
3. The third step was to determine whether the KION frame of reference detailed the content of the AI topics, e.g. in the form of learning outcomes (RQ 1.5).
4. The fourth step was to compare the KION guidelines to the international consensus with respect to the definition of AI (RQ 1.3), the AI topics to be covered (RQ 1.4), and AI-specific insights on educational vision, curriculum design, didactic methods, and the professionalization of lecturers (RQ 1.6).

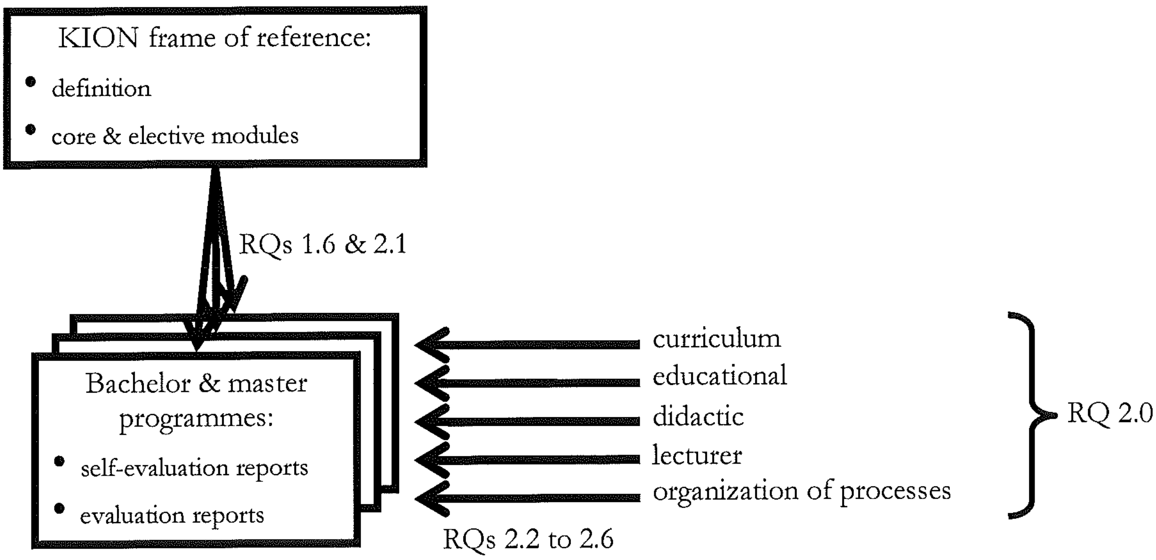


**Figure 2. RQs centring on Dutch AI bachelor and master programmes.**

Our review centring on the set of Dutch AI programmes involves three steps (see Figure 2):

1. The first step was to identify what the latest insights are on educational vision, curriculum design, didactic methods, and the professionalization of lecturers, other than those specific to AI programmes (RQ 2.0).
2. The second step was to apply the KION frame of reference to the Dutch AI programmes with respect to core and elective topics (RQ 2.1) and to any guidelines on educational vision, curriculum design, didactic methods, and the professionalization of lecturers (RQ 1.6).
3. The third step was to apply the latest insights on educational vision, curriculum design, didactic methods, and the professionalization of lecturers to the Dutch AI programmes (RQs 2.2, 2.3, 2.4, and 2.5).

## 1.5 Report structure

The structure of this report reflects the structure of the RQs. Section 1 is introductory. Section 2 gives the answers to RQs 1.0 (AI definition), 1.1 (AI topics), and 1.2 (relationship of AI to CS). Section 3 addresses the "what?" question by answering RQs 1.3 (KION definition), 1.4 (KION topics), 1.5 (detailing the KION topics), and 1.6 (KION educational guidelines). Section 4 focuses on the set of Dutch AI programmes. It addresses the "how?" question in answering RQs 2.0 (educational insights), 2.1 (compliance with KION topics), 2.2 (curriculum design), 2.3 (educational vision), 2.4 (didactic methods), 2.5 (professionalization of lecturers), and 2.6 (organization of teaching-learning processes). Section 5 identifies future directions in AI that the KION frame of reference, and the AI programmes based on it, are likely to have to anticipate. Section 6 discusses these answers. Section 7 draws conclusions and makes recommendations.

## 2. Consensus on AI definitions and topics

*In this section we investigate whether there is a widely-shared consensus on how to define AI, on what functions an intelligent system should be able to perform, on the classes of techniques that have been developed to implement such systems, and on the applications of intelligent systems.*

### 2.1 Source materials

To establish the international consensus on which this exercise was based, we surveyed leading AI journals, conferences, and textbooks, as well as overviews such as AAAI's AI Topics website and the Wikipedia pages on AI and the history of AI. All our source materials (see Table 1) were in English. We sought existing standards or guidelines for an AI curriculum or syllabus3, analogous to the ACM-IEEE Joint Task Force standards for computer science, computer engineering, software engineering, information systems, and information technology bachelor programmes (CC2005) (CS2013). We found curricula and syllabi for individual AI programmes, including several of the Dutch AI programmes, but no generic standards or guidelines applying to AI programmes at undergraduate or postgraduate levels.

**Table 1. Source materials for extracting definition and topics of AI.**

| Type of source | Source materials |
|---|---|
| AI journals | Artificial Intelligence Journal (AIJ)<br>Journal of Artificial Intelligence Research (JAIR) |
| AI conferences | International Joint Conferences on Artificial Intelligence (IJCAI)<br>Association for Advancement of Artificial Intelligence (AAAI) |
| Textbooks & handbooks | Nilsson (1980); Bundy (1980); Barr & Feigenbaum (1981); Winston (1984); Charniak & McDermott (1985); Rich & Knight (1991); Russell & Norvig (2010) |
| Overviews | AI Topics website<br>Wikipedia pages on: Artificial Intelligence; History of Artificial Intelligence |

From our source materials, we extracted definitions of AI and identified features in AI. These features fell into three categories: AI functionality (e.g. vision, reasoning, and manipulation), AI techniques (e.g. search, logic, and neural nets), and AI applications (e.g. diagnosing diseases, planning synthesis of chemicals, and playing games). There were a few features, such as AI programming languages, that did not fall into any of the three categories.

### 2.2 Defining AI (RQ 1.0)

In this sub-section we answer RQ 1.0: "What is the international consensus on the definition of AI?"

There are many definitions of AI; see the selection in
Table 2. The definitions themselves depend on the meaning of the term "intelligence", defined by the Oxford dictionaries as "the ability to acquire and apply knowledge and skills" and by Wiktionary as the "capacity of mind, especially to understand principles, truths, facts

[3] Using search strings such as: "curriculum guidelines for artificial intelligence", "standard curriculum for artificial intelligence", and "artificial intelligence syllabus" in Google. We also searched the Education Activities pages on the ACM website (http://www.acm.org/education) and the Curriculum Development pages on the IEEE website (http://www.computer.org/portal/web/education/Curricula).

or meanings, acquire knowledge, and apply it to practice; the ability to learn and comprehend".

We observe that some world-class AI conferences and journals, including the International Joint Conferences on Artificial Intelligence (IJCAI)[4] and the Artificial Intelligence Journal (AIJ)[5], do not define AI. Evidently, anyone submitting a paper to such conferences and journals is assumed to know what AI is.

**Table 2. Selected definitions of AI, in date order.**

| Source | Definition |
|---|---|
| McCarthy et al, 1955 | The science and engineering of making intelligent machines.<br>(Cited in Kolata, 1982): What is really needed are machines that can solve problems – not machines that think as people do. |
| Nilsson, 1980 | Nilsson states (p.2): "AI has embraced the larger scientific goal of constructing an information-processing theory of intelligence. If ... a *science of intelligence* could be developed, it could guide the design of intelligent machines as well as explicate intelligent behaviour as it occurs in humans and other animals."<br>This implies that there are two types of AI: (1) aimed at designing intelligent artefacts, and (2) aimed at explicating natural intelligence using computational means. |
| Bundy, 1980 | The attempt to build computational models of cognitive processes (p.ix). |
| Barr & Feigenbaum, 1981 | The part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour: understanding language, learning, reasoning, solving problems, and so on (p.3). |
| Winston, 1984 | The study of ideas that enable computers to be intelligent (p.1). |
| Charniak & McDermott, 1985 | The study of mental faculties through the use of computational models (p.6). |
| Rich & Knight, 1991 | The study of how to make computers do things which, at the moment, people do better (p.3). |
| Poole, Mackworth & Goebel, 1998 | The intelligence exhibited by machines or software. |
| Luger & Stubblefield, 2008 | The branch of computer science that is concerned with the automation of intelligent behaviour. |
| Russell & Norvig, 2010 | The study and design of rational[6] agents, where a rational agent is a system that perceives its environment and takes actions that maximize its chances of success.<br>Russell & Norvig classify previous definitions of AI into a two-by-two matrix: thinking versus acting, and (thinking or acting) humanly versus rationally. |

[4] http://ijcai.org/ (12 September 2014).
[5] http://aij.ijcai.org/ (12 September 2014).
[6] Russell and Norvig (2010) use the term "rational", but this might suggest that agents must necessarily be restricted to rational decision-making (i.e. involving exhaustive search of problem and solution spaces). There is strong evidence that human decision-making is more often intuitive ("naturalistic") than rational, especially when decisions have to be made under time pressure or using incomplete or uncertain information (Klein, 1998; 2003).

| | |
|---|---|
| Wiktionary, 2014[7] | 1. Intelligence exhibited by an artificial (non-natural, man-made) entity.<br>2. The branch of computer science dealing with the reproduction or mimicking of human-level intelligence, self-awareness, knowledge, conscience, thought in computer programs.<br>3. The essential quality of a machine which thinks in a manner similar to or on the same general level as a real human being. |
| Oxford dictionaries, 2014[8] | The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. |
| Association for Advancement of Artificial Intelligence (AAAI), 2014[9] | Mechanisms underlying thought and intelligent behaviour and their embodiment in machines. |

Most of these definitions follow McCarthy et al.'s (1955) example: AI is about making (intelligent) machines. This stance has been termed the "engineering approach".

Nilsson (1980) aims at a larger scientific goal. He argues that a science of intelligence could be developed that covers both artificial and natural systems. This opens up the possibility of taking knowledge about intelligence in humans and other animals – obtained from the cognitive sciences – and applying this knowledge in the computing sciences to create (artificial) intelligent systems. This flow of knowledge is known as the "biological metaphor". Vice versa, knowledge obtained from creating artificial intelligent systems can be applied to humans and animals, as exemplified by Charniak & McDermott's (1985) definition. We term this flow in the other direction the "computational metaphor".

Flows of knowledge between artificial and natural systems connect the computing sciences to the cognitive sciences, as depicted in Figure 3. This figure also shows the respective reference disciplines behind computing and cognitive sciences. According to CS2013[10], the computing sciences comprise computer science (CS), computer engineering (CE), software engineering (SE), information systems (IS), and information technology (IT). As the definitions show, the most important of these is CS. The reference disciplines in cognitive sciences comprise psychology, neuroscience, linguistics, anthropology, social science, and philosophy[11].

7 http://en.wiktionary.org/wiki/artificial_intelligence (14 August 2014).
8 http://www.oxforddictionaries.com/definition/english/artificial-intelligence (12 September 2014).
9 http://www.aaai.org/home.html (12 September 2014).
10 See also http://en.wikipedia.org/wiki/Computer_science (26 November 2014).
11 http://en.wikipedia.org/wiki/Cognitive_science (26 November 2014).

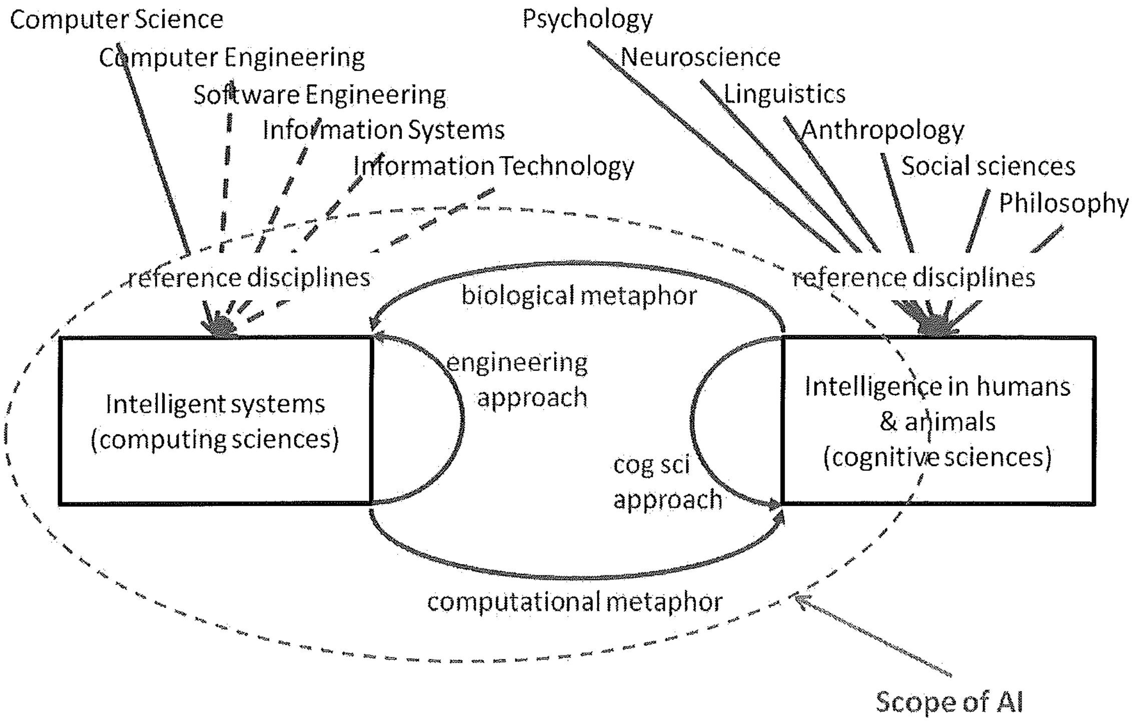


**Figure 3. Knowledge flows in the science of intelligence.**

## 2.3 AI topics (RQ 1.1)

In this sub-section we answer RQ 1.1: "What is the international consensus on the sub-fields/topics within AI?"

We look more deeply into our source materials to identify the topics of AI as a scientific discipline. Three categories of topic can be found:

- *Functionalities.* Intelligence is seen as consisting of a set of functionalities, as exemplified by the Oxford dictionaries' (2014) definition. Invariably, the set of functionalities complies with the model of an agent, namely an entity that is capable of sensing its environment, making decisions based on the sensed information, and acting appropriately. The sensing (or perception) functionalities comprise natural language processing (NLP) and computer vision. Decision-making (or cognitive) functionalities include knowledge representation (KR), reasoning (a.k.a. inference), planning, and learning. Acting (or motor) functionalities include movement and the manipulation of objects, generally lumped together as "robotics", as well as the generation of speech and text (usually included in NLP). The source materials show a high degree of consensus on these functionalities.

- *Techniques.* Over the years, a growing set of techniques has been developed to implement the above-mentioned functionalities. These techniques are often grouped into symbolic techniques, such as search and logic, and sub-symbolic techniques, such as neural nets (NNs) and evolutionary or genetic algorithms (GAs). Additional groups can be found in some sources, such as for handling uncertainty (e.g. Bayesian nets, probabilistic methods, and classifiers) and for specific types of application (e.g. control theory for control applications, constraint processing for scheduling applications, and intelligent interfaces for applications requiring interaction with human users). The source materials show a general consensus on the symbolic techniques and, to a lesser extent, on probabilistic methods.

- *Applications.* A minority of the sources mention applications. Example applications mentioned include diagnosing diseases, planning the synthesis of chemicals, solving differential equations in symbolic form, analyzing electronic circuits, financial analysis, intelligent tutoring systems, and playing games. It is not possible to identify a consensus on applications across the source materials. Recently we observe many new applications of AI not yet mentioned in the considered sources, such as the development of automated vehicles and humanoid robots.

There is a handful of other features that do not readily fall into the categories of functionality, technique, or application. First, several sources mention the tools (e.g. programming languages and AI platforms) needed to implement intelligent systems. Second, two sources mention the relationship between AI and the Web as a topic. This relationship covers both the delivery of intelligent systems over the Web and making web-based applications intelligent. The first relationship could alternatively regard the Web as a tool, and the second could be regarded as a part of intelligent interfaces.

Several sources mention multi-agent systems (MAS). While the sources employ the agent metaphor in identifying intelligent functionalities, most of them focus implicitly on a single, isolated agent, either autonomous or interacting with a human user. One indication is the emphasis on *natural* language in speech or text form, i.e. languages used by humans. Likewise, material on intelligent interfaces draws on the human-computer interaction (HCI) literature. None of the sources discuss machine-to-machine interaction or telecommunications. If the sources were extended to the MAS literature, then it is likely that additional features like these would become apparent. Additional functionalities might then include negotiation, coordination, collaboration, and the management of other agents. Additional techniques might include system-to-system interfacing, communication protocols, the generation and parsing of electronic messages, and message routing over networks, with additional supporting mathematics being drawn from telecommunications engineering, graph theory, and network science.

The table in Appendix D shows the functionalities and techniques mentioned by each of the source materials.

## 2.4 Relationship between AI and computer science (RQ 1.2)

In this sub-section we answer RQ 1.2: "What is the relationship between AI and the wider fields of computer science and cognitive science, together with their reference disciplines?"

Three of the definitions (Barr & Feigenbaum, 1981; Luger & Stubblefield, 2008; Wiktionary, 2014) regard AI as a part of computer science (CS). Moreover, the engineering of intelligent systems should be largely based on hardware developments in the computer engineering (CE) discipline and on best practices in software development from the software engineering (SE) discipline. As intelligent systems progress towards operational deployment, they will begin to have effects on the organization and people operating and using them, as well as on the society within which the latter are embedded. Examples can be seen in the operational application of machine learning algorithms in the Google's search engine and self-driving car. It would be wise to draw on the body of knowledge in the information systems (IS) discipline, and, for maintenance and support arrangements, from the information technology (IT) discipline. For this reason, in Figure 3 we have shown all five of these disciplines as the reference disciplines to intelligent systems in the computing sciences. What distinguishes CS, CE, SE, IS, and IT from one another is that mathematics provides the grounding for CS, electrical and electronic engineering for CE, engineering practices and project management for SE, organization and management sciences for IS, and operations and maintenance management for IT. Common to all five is computer program design and implementation. The significance of these links between AI on the one hand and the CS, CE, SE, IS, and IT disciplines on the other is that a US-UK task force from the ACM, the IEEE Computer Society, and the AIS have been developing curriculum guidelines for undergraduate degree programmes for at least 15 years. The latest version of the guidelines covering all five disciplines dates from 2005 (CC2005), although the CS guidelines were more recently updated in 2013 (CS2013). Confirming the link between AI and CS, the CS2013 guidelines define learning topics and outcomes for a knowledge area named "Intelligent Systems" as a part of the core of any CS curriculum. If the KION document's ambition to be a starting point for setting international standards for AI programmes is to be achieved, then it will have to be compatible with and extend the ACM-IEEE-AIS task force's CC2005 and CS2013 curriculum guidelines.

The CS2013 guidelines divide the computer science body of knowledge into 18 knowledge areas, of which Intelligent Systems is just one. CS2013 emphasizes that knowledge areas are not intended to correspond one-to-one with particular courses in a curriculum. Each course is expected to incorporate subjects from multiple knowledge areas. Therefore, the Intelligent Systems knowledge area is smaller than a complete AI bachelor or master programme.

The Intelligent Systems knowledge area comprises the following subjects:

- Fundamental issues;
- Search strategies (basic and advanced);
- Knowledge representation & reasoning (basic and advanced);
- Machine learning (basic and advanced);
- Reasoning under uncertainty;
- Agents;
- Natural language processing;
- Robotics; and
- Perception and computer vision.

As in the KION document, the CS2013 knowledge areas are divided into core and elective subjects. Demonstrating that knowledge area is just a small part of the complete course, the core of the Intelligent Systems knowledge area is just 10 contact hours, covering Fundamental issues (1 hour), basic Search strategies (4 hours), basic Knowledge representation & reasoning (3 hours), and basic Machine learning (2 hours). All the other subjects are elective.

Each subject is defined in terms of topics and learning outcomes. For example, the Knowledge representation & reasoning subject is defined as shown in the text box.

**IS / Basic Knowledge representation & reasoning**

*Topics:*

- Review of propositional and predicate logic (cross-reference Discrete Structures/ basic Logic).
- Resolution and theorem proving (propositional logic only).
- Forward chaining, backward chaining.
- Review of probabilistic reasoning, Bayes theorem (cross-reference Discrete Structures/Discrete probability).

*Learning outcomes:*

1. Translate a natural language (e.g. English) sentence into predicate logic statement.
2. Convert a logic statement into clause form.
3. Apply resolution to a set of logic statements to answer a query.
4. Make a probabilistic inference in a real-world problem using Bayes' theorem to determine the probability of a hypothesis given evidence.

Despite the frugality of this knowledge area, it is possible to map the Intelligent Systems subjects to the AI functionalities, techniques, and other features. In Table 3 we show the Intelligent Systems subjects that we have been able to map to the AI functionalities. Two points arise out of this comparison:

- The Intelligent Systems knowledge area combines knowledge representation and reasoning into one subject.
- There is no separate Planning subject in the Intelligent Systems knowledge area. Instead, planning is covered as a topic within the advanced Knowledge representation & reasoning subject. Scheduling is not covered at all in Intelligent Systems.

**Table 3. AI functionalities identified in CS2013's Intelligent Systems knowledge area.**

| Functionality | Intelligent Systems, CS2013 | |
|---|---|---|
| | Core – Tier2 | Electives |
| Natural language processing | | Natural language processing |
| Vision | | Perception & computer vision |
| Knowledge representation | Knowledge representation and reasoning (basic) | Knowledge representation and reasoning (advanced) |
| Reasoning | | |
| Planning | | |
| Learning | Machine learning (basic) | Machine learning (advanced) |
| Robotics | | Robotics |

In Table 4 we show the Intelligent Systems subjects that we have been able to map to the AI techniques. Several points arise out of this comparison:

- There is no separate Logic subject in the Intelligent Systems knowledge area. Instead, propositional and predicate logic is a topic within the basic Knowledge representation & reasoning subject, and description logics and non-classical logics are two topics within the advanced Knowledge representation & reasoning subject.
- Neural nets (and sub-symbolic representation and reasoning generally) are only partially covered in courses like machine learning, and not covered in Intelligent Systems.
- Genetic algorithms are a topic in the advanced Search strategies subject.

- Reasoning under uncertainty covers the topics of probability, Bayes' rule, Bayesian nets, Markov nets, hidden Markov models, and decision theory. Hence, this subject maps to at least two AI techniques.
- Control theory, constraint processing, and intelligent interfaces are not covered in the Intelligent Systems knowledge area.

**Table 4. AI techniques identified in CS2013's Intelligent Systems knowledge area.**

| **Technique** | **Intelligent Systems, CS2013** | |
|---|---|---|
| | **Core – Tier2** | **Electives** |
| Search | Search strategies (basic) | Search strategies (advanced) |
| Logic | | |
| Neural nets | | |
| Genetic algorithms | | |
| Bayesian nets | | Reasoning under uncertainty |
| Probabilistic | | |
| Classifiers | | |
| Control theory | | |
| Constraint processing | | |
| Intelligent interfaces | | |

In Table 5 we show the Intelligent Systems subjects that we have been able to map to the other AI features. Several points arise out of this comparison:

- Some of the topics within Tools (basic analysis, algorithmic strategies, and fundamental data structures & algorithms) are covered in CS2013's Algorithms (AL) knowledge area, rather than in Intelligent Systems.
- Web & AI and the History of AI are not covered at all in Intelligent Systems.

**Table 5. Other AI features identified in CS2013's Intelligent Systems knowledge area.**

| **Other feature** | **Intelligent Systems, CS2013** | |
|---|---|---|
| | **Core – Tier2** | **Electives** |
| Tools | | |
| Multi-agent systems | | Agents |
| Web & AI | | |
| Philosophy | | Philosophic & ethical issues |
| History | | |

The Intelligent Systems knowledge area includes one subject that does not appear to have an equivalent among the AI topics. This is the one-hour, introductory subject covering Fundamental issues, as shown in Table 6. As the KION document does not include a similar introductory module or course, it might be worth considering including an introductory core module when the document is next updated.

**Table 6. AI topics mentioned only in CS2013's Intelligent Systems knowledge area.**

| AI topics | Intelligent Systems, CS2013 | |
|---|---|---|
| | **Core – Tier2** | **Electives** |
| | Fundamental issues:<br>- Overview of AI problems & examples of successful recent applications<br>- What is intelligent behaviour?<br>  o Turing test<br>  o Rational vs non-rational reasoning<br>- Problem characteristics<br>  o Fully vs partially observable<br>  o Single vs multi-agent<br>  o Deterministic vs stochastic<br>  o Static vs dynamic<br>  o Discrete vs continuous<br>- Nature of agents<br>  o Autonomous vs semi-autonomous<br>  o Reflexive, goal-based, & utility-based<br>  o Importance of perception & environmental interactions | |

## 3. Content of Dutch AI programmes

*In this section, we address the "what?" question by looking in more detail at the content of the Dutch AI programmes. We focus on the KION document, because this aims to define what an AI programme in the Netherlands should provide as a minimum ("common core") and how it can extend this core (using "elective" courses) to distinguish itself from other AI programmes. This avoids having to extract what is common in the Dutch AI programmes.*

### 3.1 KION definition of AI (RQ 1.3)

In this sub-section we answer RQ 1.3: "Does the KION definition of AI reflect the international consensus on the definition of AI?"

The KION document's definition of AI reads as follows (section 1, p.3): "the term Artificial Intelligence as used in this document refers to the study of intelligence, whether artificial or natural, by computational means." Intelligence is seen as the ability to reason with knowledge, to plan and to coordinate, to solve problems, to perceive, to learn, and to understand language and ideas. While intelligence was originally associated with the human brain, computing technology allows it to be investigated without direct reference to the natural system.

In section 1.1 (also p.3) the document states that this definition was agreed upon as a result of sharing cognitive science (as the study of natural intelligence) and artificial intelligence (as a formal approach to intelligence) under the heading of AI in the Netherlands' Central Register of Tertiary Education Programmes[12]. This implies that the KION definition is entirely compatible with the depiction in Figure 3. However, the "computational means" is crucial. For this reason, the scope of AI in the Netherlands passes part-way through the study of natural intelligence, because the latter may be studied in ways that do not make use of computing.

### 3.2 AI topics in KION (RQ 1.4)

In this sub-section we answer RQ 1.4: "Does KION identify a set of topics for AI bachelor and master programmes that is compatible with the international consensus on the sub-fields/topics for AI study and research?" We look in turn at AI functionalities, techniques, and other features. There are also some topics mentioned in the KION document that do not appear in the international consensus.

The set of topics (also termed modules, skills, and courses) can be found in KION's page 9 under section 3.3 ("Shared background for bachelor programmes"). These are divided into a common core and elective courses. While the common core appears to be exclusive to bachelor programmes, the elective courses may be assigned to the bachelor or the master. The common core is itself sub-divided into AI modules, support modules, and academic skills. While the AI modules correspond to our AI topics, the support modules are equivalent to what we have termed reference disciplines. The academic skills are specific neither to AI topics nor to reference disciplines. While the elective courses are not sub-divided, they all seem to be AI topics.

Before comparing the KION topics with the international consensus, three immediate impressions already come to mind:

12 Centraal Register Opleidingen Hoger Onderwijs (CROHO).

1. There appear to be important omissions. For example, search, planning and scheduling, and decision making are not mentioned, although these topics might be expected to be part of the common core. Similarly, information theory and communications theory are not mentioned, although these might fall under the Computer science support module. Under the Mathematics support module, graph theory / network science is absent.

2. It is not always obvious what a module or course covers. In the KION document, modules and courses are merely named, lacking definition in terms of learning objectives and detailed topics. The precise content of some modules is unclear, as in "Autonomous systems". There would appear to be overlap between at least two pairs of modules: between Autonomous systems and Multi-agent systems, and between Probabilistic models and Reasoning under uncertainty. Without a detailed definition of modules and courses, it is difficult to be certain where the dividing line lies between them.

3. While intelligence in machines appears to be well covered by the AI topics, intelligence in humans and animals (Cognitive science and its reference disciplines – see Figure 3) seems to show some gaps. Psychology is represented by the Cognitive psychology module, Neuroscience by the Cognitive and Computational neuroscience elective course, Linguistics by the Computational linguistics module, and Philosophy by the Philosophy for AI module. However, Anthropology and Social sciences do not seem to be covered.

In Table 7 we show the KION modules and courses that we have been able to map to the AI functionalities. Two points arise out of this comparison:

1. KION combines knowledge representation and reasoning into one module. Given the complexity of these topics, it might be better to split them into two.

2. KION omits AI planning and scheduling entirely, despite contributions made to research in this area by TU Delft, RUG, and UM.

**Table 7. AI functionalities identified in KION modules and courses.**

| **Functionality** | **KION frame of reference** | |
|---|---|---|
| | **Core** | **Electives** |
| Natural language processing | | Language & speech technology |
| Vision | | Perception (computational & natural) |
| Knowledge representation | Knowledge representation and reasoning | |
| Reasoning | | |
| Planning | | |
| Learning | Machine learning | |
| Robotics | | Robotics |

In Table 8 we show the KION modules and courses that we have been able to map to the AI techniques. Several points arise:

1. A glaring omission is the KION document's failure to mention Search. This is such a basic AI technique that it, like Logic, deserves core treatment. It could be that search is covered as a part of the Knowledge representation and reasoning AI module, but without module and course definitions this cannot be confirmed.

2. Reasoning under uncertainty is a broad subject, encompassing probability, fuzzy logic/sets, the Shafer-Dempster technique, and default reasoning, amongst other topics. Because of the lack of definition of modules and courses in the KION

document, we are unable to judge whether the elective course covers all these topics. We have only been able to map it here to the Bayesian nets and Classifiers techniques. Probabilistic techniques are covered by KION's Probabilistic models elective course, again emphasizing the overlap between the Probabilistic models and Reasoning under uncertainty courses. There needs to be a reallocation of topics within these two courses and the core support module of Probability theory, e.g. to include basic topics in reasoning under uncertainty (such as probability and fuzzy logic) in the core and advanced topics in an elective course.

3. Control theory may be included in KION's Autonomous systems module, but without module definitions it is impossible to tell. If so, then control theory should be a core topic.

4. As already noted above, KION omits planning & scheduling, which is presumably why the Constraint processing technique (a.k.a. constraint propagation or constraint satisfaction) is not covered. However, given that autonomy generally requires (real-time) planning capabilities and autonomous systems is a core topic, then the omission of planning and scheduling (and the associated constraint processing techniques) is surprising.

**Table 8. AI techniques identified in KION modules and courses.**

| Technique | KION frame of reference | |
|---|---|---|
| | Core | Electives |
| Search | | |
| Logic | Logic | |
| Neural nets | | Neural nets |
| Genetic algorithms | | Genetic algorithms |
| Bayesian nets | | Reasoning under uncertainty |
| Probabilistic | | Probabilistic models |
| Classifiers | | Reasoning under uncertainty |
| Control theory | | |
| Constraint processing | | |
| Intelligent interfaces | Human-computer interaction | |

In Table 9 we show the KION modules and courses that we have been able to map to other AI features. Two points arise:

1. The KION document covers Programming and Data structures & algorithms as support modules drawn from Computer science. However, it appear to fail to address programming languages and platforms for AI.

2. There is no mention in the KION document of ethical and societal issues relating to AI. This is a gap that needs to be filled.

**Table 9. Other AI features identified in KION's modules and courses.**

| Other AI feature | KION frame of reference | |
|---|---|---|
| | Core | Electives |
| Tools | Programming<br>Data structures & algorithms | |
| Multi-agent systems | Multi-agent systems | |
| Web & AI | | Web intelligence |
| Philosophy | Philosophy for AI | |
| History | History of AI | |

The KION document lists modules and courses that do not appear to have an equivalent in the international consensus, as shown in Table 10. Some of these are AI applications, e.g. Data mining, Information retrieval, VR & gaming, and Bio-informatics. Two core modules (Cognitive psychology and Computational linguistics) and two elective courses (Cognitive modelling & architectures of cognition and Cognitive & computational neuroscience) are drawn from cognitive science reference disciplines, as noted above. While these courses are not normally regarded outside the Netherlands as AI topics, the strong grounding of Dutch AI programmes in cognitive science gives AI in the Netherlands a unique flavour. In our view, this strength is valuable, and should be maintained and exploited.

**Table 10. AI topics mentioned only in KION modules and courses.**

| AI topics | KION frame of reference | |
|---|---|---|
| | **Core** | **Electives** |
| | Autonomous systems | |
| | Cognitive psychology | |
| | Computational linguistics | |
| | Mathematics:<br>- Calculus<br>- Probability theory<br>- Linear algebra | |
| | | Cognitive modelling & architectures of cognition |
| | | Data mining |
| | | Information retrieval |
| | | Cognitive & computational neuroscience |
| | | Virtual Reality & gaming |
| | | Bio-informatics |

## 3.3 Details of KION topics (RQ 1.5)

In this sub-section we answer RQ 1.5: "Does the KION frame of reference detail the content of the AI topics, e.g. in the form of learning outcomes?"

RQ 1.5 can be swiftly answered: the KION frame of reference does not detail the content of AI topics, neither those in the core nor the electives. It simply lists the names of topics without defining or describing them in any way. In particular, no learning outcomes and topics are given, as in CS2013. Moreover, there is no indication given as to the amount of effort to be devoted to a topic, e.g. in the form of ECs.

By simply naming topics, the KION frame of reference implicitly assumes that readers will all interpret the names in the same way. This assumption may be reasonable for the support modules in the common core, such as programming, calculus, probability theory, linear algebra, and statistics. Moreover, many of the AI topics may well be unambiguous, such the Philosophy of AI and the History of AI. Without definitions or further detail, such as learning outcomes and topics, unambiguity cannot be guaranteed. Fortunately, most AI topics are defined in (for example) Wikipedia[13].

[13] Note that few of the topics are defined in the Oxford Dictionaries.

We conclude that a major problem with the existing KION frame of reference document is that the topics are not defined or described in any way. We recommend that all topics should be defined, like the Glossary of terms included in CC2005, with learning outcomes and detailed topics listed as in CS2013.

## 3.4 KION guidelines on educational aspects (RQ 1.6)

In this sub-section we answer RQ 1.6: "Does the KION frame of reference give any guidelines on educational aspects, such as the educational vision, curriculum design, didactic methods, and/or the professionalization of lecturers specific to AI bachelor and master programmes?"

Section 2.4 of the KION frame of reference provides some interesting statements about didactics. In most of the critical reflections, however, this topic was not highlighted. Interesting didactic approaches have been used, but the description of the underlying didactic model is hardly described and evaluated. The selection of the right AI topics is important, but the way these topics are presented are of equal importance to educate students to become AI experts. In the next update of the KION document, the section on educational aspects should fill a complete chapter. It is assumed that all universities will accept the updated KION document as a general guideline for the design of their AI programmes. A few comments on the KION guidelines are as follows:

- The current version of the KION prescribes that AI programmes use a didactic model that encourages students to acquire knowledge and skills on their own. Furthermore, the KION report prefers a teaching methodology which emphasises learning rather than teaching. One would expect a less extensive use of teaching methods like oral lectures, which focus on knowledge transfer.
- The KION document states that the AI curriculum should be structured and designed in such a way that it will adapt almost automatically to new scientific requirements, and changes in the characteristics of the student population or changes in study environment and conditions. In the next KION document, possible models and procedures should be presented.
- Students should be prepared for lifelong learning by training students' attitudes and ways of learning and offering them specific strategies where to find the right information and staying current in the field.
- One of the most interesting statements in the KION section on didactics is about encouraging cooperative learning and the use of communication technologies to promote group interaction. Our proposed didactic model (discussed under 4.5) is in line with this statement.
- In the KION document a list of core courses/topics for bachelor programmes are presented. What is missing is the link and knowledge transfer between different courses. Currently they are presented as stand-alone courses and the integration of different knowledge areas is generally left to the students. It is also desirable to define the learning lines between different courses.
- The learning goals of different courses should be defined in an explicitly operational way, in order to guarantee that the goals are met during the course and adequately monitored by the assessments. This also holds for the general goals related to attitude building. Usually these goals are implicitly tested or it is assumed that these goals are satisfied if students complete the study programme.
- As the programme's intended learning outcomes are distributed over different courses, it might be wise to present guidelines defining which learning goals might be expected in which phase (year) of the bachelor programme.

## 4. Educational Aspects of Dutch AI programmes

*In this section, we address the "how?" question. We start by looking at the latest insights into the educational aspects of bachelor and master programmes in general (not specific to AI). Then we look at the compliance of the Dutch AI programmes with the AI functionalities and techniques in the KION frame of reference. Next, we look at curriculum design, educational vision, didactic models, the professionalization of lecturers, and the organization of the educational process.*

### 4.1 Latest insights on educational aspects (RQ 2.0)

***Educational Adagio***
*We teach today's students*
*With yesterday's knowledge*
*For a future we don't know* (a well-known saying)

In mathematics it is still common use to lecture with blackboard and chalk. The use of PowerPoint presentation is not common practice. In a course on calculus a lecturer shows how to solve mathematical problems by providing many examples. The idea is that students learn by imitation. Over the years it proves to be a successful method. In courses on psychology a lecturer reports about famous experiments. In this way he/she hopes to introduce students in experimental psychology. A good lecturer in philosophy or history is supposed to provide and deconstruct narratives. Lecturers in different disciplines have developed over the years their specific, but effective and efficient way of lecturing.

The educational process is very dynamic. Attractive and effective teaching methods and books lose their attraction after just a few years. This implies that the process of teaching-learning will never stabilise but is always changing. To teach AI to students, it is necessary to have a clear concept of the content, a list of topics at different levels, the time spent on a topic, and a frame of reference, showing how to fuse the different topics together. Next, a lecturer should have the abilities for and ideas on how to present the different topics to his/her students. An individual course should be part of a curriculum where different courses are organised and related to each other in such a way that they fulfil target goals and requirements. The outcome of the teaching-learning process should be assessed and the process should be evaluated continuously. In this section we discuss the different topics in more detail. The kernel of the teaching-learning process is the didactic model.

Most universities use some form of 'blended learning' in their teaching-learning environment. The didactic concept of 'blended learning' is about the integration of classical classroom teaching and online learning. In this report we focus on online learning as source and facilitator of didactic innovation. Recently a new phenomenon is emerging in academic education: learning communities, social learning, communication, collaboration, creativity, and convergence. The Ho et al (2012) report researched social networking as an educational tool. Social interaction and social presence are essential in open and online learning. Social presence is defined as the degree of connection between people within an interaction, or the sense of being there if at a distance. (Short, Williams & Christie, 1976) (Lowenthal, 2010). They state that the importance of the sense of presence has been established between students' perceptions of negative experience such as social isolation and high drop rates in e-learning. Social presence is the critical factor to stimulate the sense of community in online courses.

The concepts of learning communities and social learning have been researched by many authors. Holmes and Gardner (2006) provide an introduction to e-learning , an overview and its applications. They found that theories of behaviourism, cognitivism and socio-constructivism together with the contributions of Bruner, Piaget and Vygotsky are on the basis of most e-learning didactic models. They state that most e-learning didactic models are currently centred on the concept of communal constructivism. In communal constructivism, each member of the community learns with and from each other as well as contributing resources to the learning community. The key-factor is the provision of enhanced communication and the creation of environments within which new understandings can be fostered and developed. In recent years constructivism has extended the traditional focus on individual learning to address collaborative and social dimensions of learning.

Social media enable social learning. Pedagogy 2.0 integrates Web 2.0 tools that support knowledge sharing, peer-to-peer networking, and access to a global audience with socio-constructivist learning approaches to facilitate greater learner autonomy, agency and personalisation (Morgan, 2009) (Cochrane & Bateman, 2009) (McLoughline & Lee, 2008). Similar functionalities can also be realised by more traditional e-learning tools such as BlackBoard. But the main difference is that BlackBoard has been licensed by the universities and only students have access. Open, online learning modules are accessible by everybody, not only those enrolled as students.

Dalsgaard and Paulsen (2009) discuss the potential of social networking within cooperative online education. They state that transparency is a unique feature of social networking. It provides students insight into each other's actions. The authors argue that cooperative learning can be supported by transparency. The authors consider transparency as means to promote affinity to learning community. They consider next to affinity, social presence as an important concept. It is important that students are visible and accessible. The learning system should suggest partners that make cooperation interesting. Dalsgaard and Paulsen argue that the pedagogical potential of social networking is the possibility to create awareness among students.

## 4.2 Compliance with KION topics (RQ 2.1)

In this sub-section we answer RQ 2.1: "To what extent are the KION's core and elective AI topics covered by one or more of the Dutch bachelor and master programmes?"

The KION frame of reference defines a minimal basis for all AI programmes. In the tables 8, 9 and 10 we defined an extension of this minimal core. In this section we are not interested in individual AI programmes but the set of AI programmes as a whole. We researched in how far the current AI programmes include the set of functionalities, techniques, and other features. To check if features are present in an AI programme is not easy. Many features are distributed over several courses. There are introductory courses and advanced courses. In order to provide a fully informed comparative table, the presence of features should be scored on a gradual, ordinal scale. But we do not have access to all the learning material. Hence, our assessment is based on the description of the courses in the study guides. Almost all AI programmes have one or more variants. Students are free to choose. But this implies that not every AI student takes the same programme. Another problem is the elective courses. Students have the freedom to select some courses based on their interest or planned specialisation. There is not a fixed programme for all the students. These courses are not listed in our tables. A final problem is that different courses are not always multiples of 3 ECTS points.

The assumption is that all AI bachelor programmes provide access to all AI master programmes. But some universities require students to do special or additional courses to repair deficiencies in their bachelor programmes. It is not our goal to advocate a uniform AI programme for all participating universities. We realise that AI programmes are embedded in other programmes and faculties. If a university has a strong group in neuroscience, cognitive psychology, or philosophy, the quality of the AI programme will be enhanced by selecting courses from these other programmes.

All AI programmes have to decide on a common core of features that must be included at least on a basic level. For this reason, we provide the information in Table 11, Table 12, and Table 13. Where there are many variants, we chose the most basic one. In the tables are presented possible individual programmes, satisfying the rules defined by the faculty. Many variants are possible, but we select only some examples. This is rather arbitrary. But again the goal of this section is not to present all possible AI variants, but to give a flavour of the AI programmes. Another reason is that we want to present a survey of all features represented in different AI programmes in the hope that other AI educators will reflect on possibly including the new features in their programme.

### 4.2.1 Features identified in bachelor programmes

In Table 11 we show the functionality topics identified in the basic variants of the six bachelor programmes. Core topics are shown in **bold**. Considering the set as a whole, we observe that all the functionalities are covered in at least two bachelors. Even planning – which the KION frame of reference omits – is covered by three bachelors. Knowledge representation & reasoning and machine learning, the two topics identified as core in the KION document, were not fully covered by all six bachelors.

**Table 11. AI functionalities identified in the bachelor programmes.**

| **Functionality** | **BSc-KI (RUG)** | **BSc-KI (UU)** | **BSc-AI (RUN)** | **BSc-KE (UM)** | **BSc-AI (UvA)** | **BSc-LI (VU)** |
|---|---|---|---|---|---|---|
| Natural language processing | KIB.ATW03<br>KIB.TST03<br>LIX015B05 | CK2W0004<br>CK1W0012<br>200300434<br>CK3W3078 | BPSBR41 | | 5082TATA6Y<br>5082SPSY6Y<br>5082DISC6Y<br>5082NTIT6Y | A3-1 |
| Vision | | 200300072 | | | 5082COVI6Y | |
| **Knowledge representation** | KIB.KI103 | KI2V12009 | BKI120<br>BKI312 | KEN1210 | 5082KENN6Y<br>5082COLO6Y<br>5082ILSO6Y | |
| **Reasoning** | | CK3W3071 | IPK001<br>IPI004<br>BKI312 | KEN2230 | 5082COLO6Y<br>5082ILSO6Y | B1-3<br>E3-1 |
| Planning | | | BKI212 | KEN3410 | 5082LOPZ6Y | |
| **Learning** | KIB.KI203 | CK1W0008 | BKI120<br>BKI230a<br>IBI008 | KEN2240 | 5082LERE6Y | C3-1 |
| Robotics | KIB.AS03 | | BKI115A<br>BKI242 | KEN3236 | 5082ZOSB6Y<br>5082AUMR6Y | |

In Table 12 we show the AI techniques identified in the basic variants of the bachelors programmes. Considering the set as a whole, we observe that all but one of the AI techniques are covered in at least one Dutch bachelor. The technique that no Dutch bachelor offers is the elective Genetic algorithms (a.k.a. Evolutionary programming). In addition, only one bachelor offers a course in Control theory and two bachelors offer a Bayesian nets course.

**Table 12. AI techniques identified in the bachelor programmes.**

| **Technique** | **BSc-KI (RUG)** | **BSc-KI (UU)** | **BSc-AI (RUN)** | **BSc-KE (UM)** | **BSc-AI (UvA)** | **BSc-LI (VU)** |
|---|---|---|---|---|---|---|
| **Search** | KIB.KI103 | | BKI120<br>BKI212 | KEN2220 | 5082LOPZ6Y<br>5082ZOSB6Y | |
| **Logic** | KIB.ILOG03<br>KIB.VL03<br>LIX003B05 | CK1W0010<br>INFOLAI<br>CK3W3071 | IPK001<br>IPI004 | KEN1530<br>KEN3231 | 5082INLO6Y<br>5082COLO6Y<br>5082ILSO6Y | C1-2 |
| Neural nets | KIB.NNKI03<br>PSBAI-11 | CK1W0008 | BKI230a<br>IBI008 | | 7204MP12X<br>5082LERE6Y | |
| Genetic algorithms | | | | | | |
| Bayesian nets | | | BKI120<br>BKI212<br>IBI008 | KEN2230 | | |
| Probabilistic | WISTAKI-07 | CK2W0006 | BPSST10<br>BPSST20 | KEN2130<br>KEN2530 | | B2-1 |
| Classifiers | | | IBI008<br>BKI323 | KEN2240 | | C3-2 |
| Control theory | | | | KEN2430 | | |
| Constraint processing | INBIMP-09 | CK1W0003 | IPI002 | KEN2420 | | B1-1 |
| **Intelligent interfaces** | | 200300072 | BKI114<br>BKI323 | KEN2410 | | C2-2 |

In Table 13 we show the other AI features identified in the bachelors. All of these features are covered in at least three Dutch bachelors. All bachelors offer the core topics of Tools and Philosophy of AI.

**Table 13. Other AI and supporting features identified in the bachelor programmes.**

| **Other AI feature** | **BSc-KI (RUG)** | **BSc-KI (UU)** | **BSc-AI (RUN)** | **BSc-KE (UM)** | **BSc-AI (UvA)** | **BSc-LI (VU)** |
|---|---|---|---|---|---|---|
| **Tools** | KIB.CP06<br>INBOGP-08<br>KIB.WBV06<br>KIB.OZM10 | INFOFP<br>CK1W0007 | BKI201<br>BKI301 | KEN3234 | 5082LOPZ6Y<br>582LEBE6Y<br>5082KBMS6Y | A1-2 |
| **Multi-agent systems** | KIB.KT03 | INFOB3IS | BKI115a<br>BKI242 | KEN3430 | | C2-3 |
| Web & AI | | | | KEN3140 | 5062WEDA6Y | C1-4 |
| **Philosophy** | KIB.ORKI03<br>FI053CW | CK10009<br>WB1BD3035<br>WY2V11008<br>WB2BD3034 | BKI243 | KEN2120 | 5082FIAI6Y | E2-1 |
| **History** | INBOI-08 | | BKI101 | | 5082INKI6Y | E2-2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Computer science | | CK1W0003<br>CK1W0007 | IPI004<br>IPI005<br>IBI008<br>IBC015<br>IPC014<br>IPC015<br>IPK001<br>BKI324 | KEN1120<br>KEN1220<br>KEN1420<br>KEN1520<br>KEN2110<br>KEN2130<br>KEN2420<br>KEN2510<br>KEN3130<br>KEN3235<br>KEN3450 | 5082IMOP6Y<br>5082COSY6Y<br>5062DATA6Y | C1-1<br>C1-3<br>C2-1<br>C2-4 |
| **Mathematics** | WICALKI-11<br>KIB.NF07 | CK1W0006 | BKI104<br>BKI316 | KEN1130<br>KEN1410<br>KEN1440<br>KEN1540<br>KEN2220<br>KEN2430<br>KEN2520<br>KEN2530<br>KEN3233<br>KEN3410 | 5082LIAL6Y<br>5082COWS6Y | B1-2<br>B2-2 |
| Cognitive Sciences | KIB.AVI03 | CK1W0009 | BKI110A<br>BPSBR10<br>BKI246<br>BPSGE30<br>BKI211 | KEN1210<br>KEN1430 | 5082INCP6Y<br>5082BRCO6Y | A1-1<br>A2-1<br>A2-2<br>B2-1 |

### 4.2.2 Features identified in master programmes

In Table 14 we show the functionality topics identified in the Dutch masters programmes. Considering the set as a whole, all functionalities, except for Planning, are covered in at least two Dutch masters.

**Table 14. AI functionalities identified in the master programmes.**

| Functionality | MSc-KI (RUG) | MSc-KI (UU) | MSc-AI (RUN) | MSc-KE (UM) | MSc-AI (UvA) | MSc-AI (VU) |
|---|---|---|---|---|---|---|
| Natural language processing | Language modelling<br><br>Sound recognition | Logic, language, cognition | Text-Mining, Computer assisted language learning, Multi-lingualism, Word Recognition and Production | | Natural language processing 1 | |
| Vision | Handwriting-recognition | | Perception | | Computer vision 1<br>Computer vision 2 | |
| **Knowledge representation** | | Conceptual semantics | Cognition & complexity<br>Bayesian networks | | | Knowledge engineering |
| **Reasoning** | Arguing agents<br>Automated reasoning | Common sense reasoning | | | | Automated reasoning |

| | | | | | | |
|---|---|---|---|---|---|---|
| Planning | | Intelligent agents | | | | |
| **Learning** | Machine learning | Learning in computa-tional linguistics | Machine learning in practice , Statistical Machine learning, Bayesian neuro-cognitive models | Relational learning | Machine learning 1 Machine learning 2 | |
| Robotics | Cognitive robotics | | Human-robot interaction | Autono-mous systems | | Advanced self-organisation |

In Table 15 we show the AI techniques identified in the master programmes. Considering the set as a whole, we observe that the elective Constraint processing is not covered. All the other techniques, including all the core techniques, are covered at one or more Dutch universities.

**Table 15. AI techniques identified in the master programmes.**

| **Technique** | **MSc-KI (RUG)** | **MSc-KI (UU)** | **MSc-AI (RUN)** | **MSc-KE (UM)** | **MSc-AI (UvA)** | **MSc-AI (VU)** |
|---|---|---|---|---|---|---|
| **Search** | | - | | Intelligent search | | |
| **Logic** | Dynamic logic | | | Foundations of agents | | Advanced logic |
| Neural nets | Neural networks | | Bayesian neuro-cognitive models | | Machine learning 1<br><br>Machine learning 2 | Neural Networks |
| Genetic algorithms | | Evolutionary algorithms | Bioinspired algorithms | | | Evolutionary computing |
| Bayesian nets | | Bayesian nets | Bayesian networks | | Bayesian natural language processing | |
| Probabilistic | | | | Stochastic decision making<br><br>Identification<br><br>Game theory | Machine learning 1<br><br>Machine learning 2 | |
| Classifiers | | | Statistical machine learning | | Machine learning 1<br><br>Machine learning 2 | |
| Control theory | Signals and Systems | | Motor control | Topics in computation and control | | |
| Constraint processing | | | | | | |
| **Intelligent interfaces** | | | Advances in HCI Human-robot interaction | | | |

In Table 16 we show the other AI and supporting topics identified in the master programmes. All topics are covered by one or more Dutch masters.

**Table 16. Other AI and supporting topics identified in the master programmes.**

| Other AI feature | MSc-KI (RUG) | MSc-KI (UU) | MSc-AI (RUN) | MSc-KE (UM) | MSc-AI (UvA) | MSc-AI (VU) |
|---|---|---|---|---|---|---|
| **Tools** | | | Information retrieval | | | Large-scale data engineering<br><br>Model based intelligent environments |
| **Multi-agent systems** | Multi-agent system<br><br>Design of MAS | Intelligent agents<br><br>Multi agents systems | | Multi-agent systems | Autonomous agents 1<br><br>Autonomous agents 2 | Comparative modelling |
| Web & AI | Semantic web technology | Social semantic web | AI at the web-scale | Semantic Web | Information retrieval 1 | Intelligent web applications |
| **Philosophy** | | Philosophy of AI | Theoretical cognitive science: science and society, Philosophy of mind and language | | | |
| **History** | | | | | | History of digital cultures |

In addition, we identified some courses in the Dutch master programmes that related to the supporting topics (a.k.a. reference disciplines of computer science and the cognitive sciences) in the KION frame of reference, as shown in Table 17. No master courses in the Mathematics discipline were identified.

**Table 17. Reference disciplines / supporting topics identified in the master programmes.**

| Reference disciplines | MSc-KI (RUG) | MSc-KI (UU) | MSc-AI (RUN) | MSc-KE (UM) | MSc-AI (UvA) | MSc-AI (VU) |
|---|---|---|---|---|---|---|
| Computer science | | Models of computation | | | | Distributed algorithms |
| Cognitive Sciences | Perception<br><br>Cognitive engineering<br><br>Cognitive modelling<br><br>User models | Methods in perception | Cognition & complexity<br><br>Artificial and natural music cognition<br><br>Social neuro-cognition<br><br>Behavioural decision making<br><br>Behaviour regulation<br><br>Neuroimaging | | | Brain imaging<br><br>Human information processing<br><br>Neural models of cognitive processes,<br><br>Seminar cognitive neuroscience<br><br>Special topics cognitive science |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Computational neuroscience<br><br>Emotion | | | |

Finally, there were some courses in the Dutch master programmes that covered topics that were listed only in the KION frame of reference, such as data mining, information retrieval, and Virtual Reality and gaming, as shown in Table 18.

**Table 18. KION-only topics identified in the master programmes.**

| KION-only topics | MSc-KI (RUG) | MSc-KI (UU) | MSc-AI (RUN) | MSc-KE (UM) | MSc-AI (UvA) | MSc-AI (VU) |
|---|---|---|---|---|---|---|
| Data mining | | Data mining | | Data mining | | Data mining |
| Information retrieval | | | Information retrieval | Information retrieval | Information retrieval 1<br><br>Information visualisation | |
| Virtual Reality & gaming | | | | | Technology for games<br><br>Scientific visualisation and virtual reality | |

Comments:

1. In the study guides all possible programmes are presented. The overall view might give the impression that all features/techniques are present. This may be true, but a student has to make a selection and then we observe many gaps. For every university we selected a programme of an individual student - not the programme of an outlier student with a lot of individual choices mostly outside the area of AI, but the typical programme of a student in the kernel of AI. Most programmes allow students to compose individual programmes, and to choose a topic for their master thesis. But this may result in an individual programme which can hardly labelled as an AI programme. Our conclusion is that a bachelor programme should contain all the required features. A minimum requirement for a master programme / thesis should be that it fits in the area of AI.
2. It is difficult to find a match between the features / topics and the courses. The features are not specified, and some courses include more than one feature.
3. Many features are missing. For example, there are many courses on research methods, and corresponding features are missing.
4. Many courses are definitely AI courses with respect to the definition of AI, but some corresponding features are missing.

## 4.3 Curriculum design (RQ 2.2)

In this sub-section we answer RQ 2.2: "How well do the Dutch bachelor and master programmes on AI design their curriculum in a uniform way?"

The design of a curriculum is an interaction of two processes:

- On the one hand, a designer studies AI curricula of famous universities. As an AI expert he/she has a good overview of the field of AI, the research and application in that field. The designer has a good overview of possible careers and requirements of industry and society. This process would end up in an AI curriculum which is at the basis of all AI curricula.
- On the other hand, there is a process of individualisation. A designer has his/her preferences, his/her colleagues within the AI team have a specific background and specialisation, and he/she wants to design a curriculum which is not just a copy, but a curriculum with its own identity. It should also be of interest to students.

In a melting process of both streams a new curriculum has been born. The next step is to formalise the new curriculum, to define its goals, educational view, learning outcomes. The different topics have to be distributed over the different courses and the courses find their place in a scheme satisfying all time constraints and input-output requirements. Educational consultants, not necessarily having an AI background, can play a valuable role in this process. They also take care that the curriculum satisfies the requirements and rules set by the university.

From what has been stated above it is clear that designing a curriculum is a complex process with many requirements and constraints. The KION report and the agreement of all participating universities are unique. The next step is to take care of an update of the KION report and to make sure that the deviant programmes are within limits. It is possible to update the KION report after some ample discussions. But to agree that all AI partners take this KION report and for example agree that 20% of the curriculum is according to the basic programme defined in KION is a much more complicated process.

In this report we advise to update the KION report and the AI curricula on the following points:

- Delete outdated features and add new ones. From the current curricula it can be concluded that most curricula use new features which are still not defined in the KION report.
- Design a common digital AI curriculum. This can be composed of contributions from AI partners.
- Use existing MOOCs or parts of it in current curricula as blended learning.
- Design one or more MOOCs on AI. These MOOCs can be designed by individual partners or as a joint effort with AI partners.

## 4.4 Educational vision (RQ 2.3)

In this sub-section we answer RQ 2.3: "How well do the Dutch bachelor and master programmes on AI define, implement, and evaluate their educational vision in comparison with international best practices?"

All the universities visited have their own didactic principles as a *leitmotif*. In this section we present a summarization, taken from the Critical Reflections 2013. We noticed that many more documents were available on the general websites of the university, but this was beyond the scope of our interest. Our goal is to inform all AI departments about the didactic concepts as reported in their critical reflections. Next, we will discuss how these concepts have been implemented at the AI departments, how the lecturers are trained to use this concept in their teaching, and how the didactic concept has been evaluated. We hope and expect that the didactic concepts find a place in the next KION frame of reference.

An overview of all didactic concepts used by the different Dutch AI programmes can be found in Appendix A. Maastricht University has the most explicitly defined and implemented didactic concept. The AI department defined an adapted version of this concept. Parallel to the courses students learn to apply the knowledge lectured in the courses in realistic and challenging projects. At other universities students also get practical assignments and are involved in project work, but the relation knowledge-practical is not as strict as at UM. Other universities use blended forms of their didactic principles and we noticed that some lecturers take the freedom to lecture in their own way.

Evaluation of the didactic principles has not been reported upon in the Critical Reflections. From discussions with lecturers during the site visits it became clear that the teaching-learning outcomes of individual courses are based on the interests and expertise of lecturers and discussed in staff meetings. These discussions are more problem centred. The general didactic principle and the gradual implementation of this principle and changes in learning behaviour of students have not been assessed in an explicit way. The student surveys are focussed on the content of teaching and learning.

At the universities, novice lecturers get a special training how to use the didactic concept. In the (advanced) University Teaching Qualifications (Dutch: Basis Kwalificatie Onderwijs, BKO) courses lecturers are trained how to use different ways of teaching, how to define their teaching-learning goals and how to evaluate them. From the Critical Reflections it is not clear how explicitly the didactic principle defined at the university will be trained.

At this moment written exams are used for grading students, to assess whether the (learning content) goals and curriculum specific skills are obtained at a satisfactory level. Recently, written exams are also used to assess if the more academic skills are obtained (see Learning analytics (Educause, 2010)).

### 4.5 Didactic models (RQ 2.4)

In this sub-section we answer RQ 2.4: "How well do the Dutch bachelor and master programmes on AI determine the appropriate didactic methods for AI subjects consistent with their educational vision?"

At this moment the different AI departments each have their own characteristic didactic model (see also Section 4.4). This model should be used by all lecturers in their teaching process. Most lecturers use models inspired by the models they experienced as students. Or they use didactic models in an intuitive, less explicit way. Most lecturers agree that students should be educated as scientists and as AI experts. For some of them it is questionable if they have an important role in the personal development of their students. Different teaching modes are used, but, with exception of Maastricht University, most lecturers focus on individual instruction in their lessons inspired by different didactic models, such as mastery learning, drill and practice models, or blended models, etc. The main goal is to educate students as individual researchers.

After graduation many students find a job in industry, government, commerce, teaching, etc. Education as an individual scientist may be the best education for such professions, but in addition to problem solving, critical thinking and other abilities are required, such as the abilities to cooperate in networks and projects, to communicate, and to negotiate. In many national or European research projects, the focus is on cooperative research. So pertinent questions are: do we still have to educate students as passive consumers of content or as active co-producers of knowledge? Do we have to train students how to read scientific books and papers or how to use web technology to acquire knowledge? We observed many forms of blended teaching-learning models, but in the near future didactic models will be needed with a focus on student-centred learning and user-driven education. In Figure 4, we depicted how, borrowing ideas from social networks, the central role of the lecturer as designer, coordinator, and manager of the learning-teaching process (interacting in a blended-learning process with a 'cloud' of students) will be replaced by an educational network of "study-friends" (a potentially much larger, world-wide 'cloud' of students who will primarily interact with each other and the online material, once provided by the teacher). Bottom-up learning processes will replace the top-down approach currently used by universities.

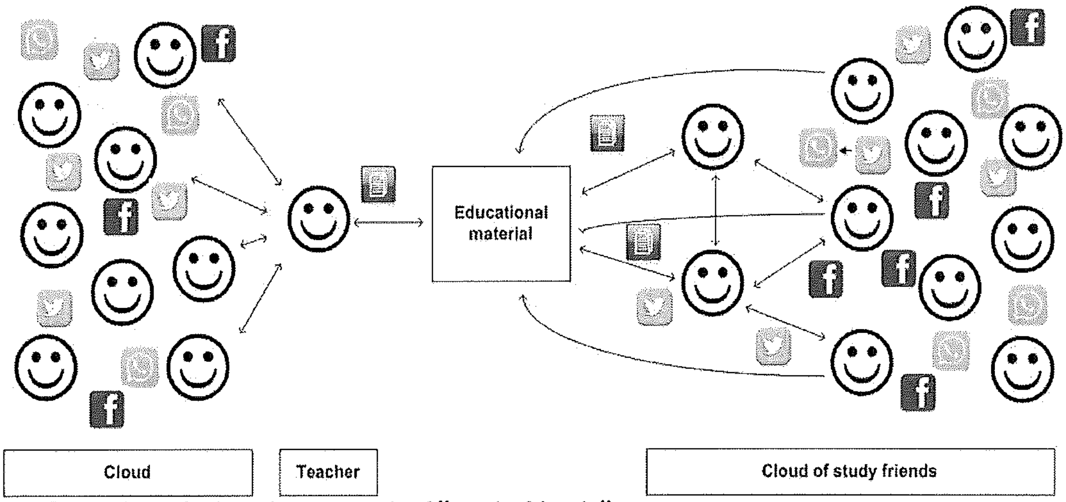


**Figure 4. Depiction of education network of "study-friends".**

Looking beyond the six Dutch universities we visited, we observe an exponential growth of Massive Open Online Courses (MOOCs). The MOOC on Artificial Intelligence designed by the famous AI expert Sebastian Thrun (CEO of Udacity and professor at Stanford University) attracted more than 100.000 students. Another interesting MOOC is the University of Edinburgh's course on AI planning, authored by Austin Tate and Gerhard Wickler. The course aims to provide a foundation in AI techniques for planning, with an overview of a wide spectrum of different problems and approaches, including the underlying theory and some applications. The University of Edinburgh offers many MOOCs via Coursera. Globally, many top universities are forming consortia to design MOOCs such as edX, MITx, Harvardx, Coursera and Udacity[14].

In the Netherlands, Delft University of Technology already offers more than ten MOOCs on different topics. The learning material is distributed via worldwide network of connecting students. They have access to the material anytime, anywhere, with communication via social media playing an important role. For example, traditional e-learning platforms such as Blackboard now incorporate social media functionality, supporting instant messaging and the formation of interest groups. Even NVAO is showing interest in the development of

[14] See http://www.skilledup.com/articles/the-best-mooc-provider-a-review-of-coursera-udacity-and-edx/.

MOOCS[15]. So MOOCs and the provision of teaching material through open, online courses could well be points of discussion during the next accreditation round.

## 4.6 Professionalization of lecturers (RQ 2.5)

In this sub-section we answer RQ 2.5: "How well do the Dutch bachelor and master programmes on AI ensure the continuing professionalization of their lecturers consistent with their didactic methods?"

From an AI lecturer we may expect that he or she is an expert in the area of AI. Because research and education are two sides of the same coin, it is necessary for an AI lecturer to be involved in AI research. In that case he/she is able to illustrate his/her lectures with findings from his/her own research. A lecturer should be a role model for his/her students. When the goal of AI education is to educate students as AI scientists, the lecturer should also be able to play the role of AI scientist.

Students have to find their passion, a study should inspire them, providing them creativity and motivating them. One of the main tasks of a lecturer is transmitting knowledge. But a lecturer is also a tutor for his/her students guiding them in their educational growth as human beings and as scientists. Peer students also play an important role in the learning process. In didactic models that are based on social learning, students learn from one another by cooperation and interaction, often using social media through Web 2.0 technology.

During our visits, we saw that several AI lecturers at different universities are well-known AI researchers. Students describe them as enthusiast, inspiring experts. This proves that they were able to introduce their students to AI. Most lecturers present their lectures in a content-centred approach and not in a student-centred learning approach. Because lecturers are AI experts, they have a global overview of the areas of AI and of the topic of their lectures in more detail. The different topics are presented in alignment with the written lecture material or according to AI theory. They present the learning material in the way an AI expert does or should do. But there is a difference in presenting an AI topic as a survey or as learning material to students. The lecturer should be aware of his/her didactic model but also of his/her teaching goals. In discussions with lecturers one of the most positive aspects of BKO training was reflection on their learning goals. Even lecturers with many years of teaching experience had to admit that, thanks to their BKO courses, their intuitive way of lecturing had been upgraded to a higher level. A more detailed outline of their lectures based on reflection and on critical analysis of their own teaching behaviour is at the base of the teaching process. It is also necessary to write the goals down in an explicit and operational way, enabling them to be testable. Ill-defined goals results in vague evaluation.

In Section 4.5 we discussed a social learning network of students. There should also be a social teaching network of lecturers. Via such a network, lecturers can inform each other what is going on, exchanging information about courses, time schedules, activities, etc. Most importantly, lecturers should discuss a common didactic model and the synergy between different courses. Via such a network, lecturers are able to cooperate and to learn from each other, as assumed in social network learning. Most lecturers are not fully aware about the content of their colleagues' lectures, the different teaching styles they use, and any incidents or problems. It is not commonly done to visit each other's lectures. The network should not be restricted to one university, but should include all AI sections in the Netherlands. This

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15 http://www.nvao.net/page/downloads/NVAO_Verkenning_MOOCs_en_online_HO_juni_2014.pdf (6 October 2014).

would complement existing yearly meetings or conferences. A similar process has been started at secondary schools, initiated by two teachers (Kneyber & Evers, 2014).

## 4.7 Organization of education process (RQ 2.6)

In this sub-section we answer RQ 2.6: "How well do the Dutch bachelor and master programmes on AI organize their teaching and learning processes?"

An important aspect is the assessment of the outcomes of the teaching-learning process via summative and formative evaluation procedures. It is necessary to define schedules and procedures for how the teaching learning process is organised, including the examination. We observed that most of the universities we visited use questionnaires to evaluate the teaching process. The results of these questionnaires are basic performance indicators. Problems in the teaching process can also be detected by interviewing students. Learning analytics theory points to other ways of assessing the outcomes of the teaching-learning process. Every university employs written exams. The end results are used as performance indicators of the teaching-learning process. Written exams, reports, and the results of assignments provide a rich source for assessments that is hardly exploited. Take for example the bachelor and master thesis. Most universities use a grading system or a grading system of different aspects such a scientific level, presentation, AI aspects etc. But we did not observe the outcome of the grading system being used in a systematic way as feedback into the teaching-learning process. Questionnaires are analysed using statistical methods and tools, but the results of the examination process are not yet analysed and reported in a scientific way. Most universities use incident-based methods. Questionnaires are specially designed for evaluation, but the response is usually low. Exams or the results of assignments are available, but the analysis is a more complex process (Educause, 2010).

The process of examination is an important item in the NVAO evaluation procedure and especially in the formalisation of that process. We noted that assessment of the outcomes of the teaching-learning process can only be done if the goals and target points have been clearly defined. We observed that, thanks to the BKO training, the goals for individual courses are well defined. The global goals are also well defined, thanks to KION's frame of reference. Some universities use a matrix structure, where the columns correspond to the courses and the rows to the educational goals. Although all goals are equal, some are more equal than others. It is impossible to realise all the goals in every individual course. So some differentiation is needed. A first attempt to realise that is to enter numbers on an ordinal 3 or 5-point scale into the cells within the matrix to indicate the importance and appearance of a specific goal in a course.

# 5. Future of AI

*In this section, we identify the trending AI topics (the "what") and educational aspects (the "how") that we believe will become more prominent on a timescale that will encompass the next accreditation process, i.e. between now and 2020.*

## 5.1 What

AI is a fast-moving field. This requires the developers of AI bachelor and master programmes to take a view on what new topics to include and on what existing topics may be dropped or combined. Developers need to identify trends, modifying their programmes as necessary to cover topics that students may encounter after graduation. Changes may have to be made faster than the six-year evaluation periodicity.

By brainstorming and looking at special tracks in forthcoming AI conferences (e.g. FLAIRS-28 to be held in 2015), we identified a variety of trends that we believe developers will need to consider before 2020. These trends, not listed in any particular order, are as follows:

1. Big data
2. Autonomous systems
3. Sensor networks
4. Human-robot teams
5. Affective computing
6. Agent-based modelling
7. The use of solvers

Two of these trends are already addressed in the existing KION frame of reference, i.e. big data (in the form of the Data mining elective) and autonomous systems (a core topic). However, what concerns us here is their combination in recent developments both in the commercial world and within governments. There appears to be an emergent line of thinking that systems can be made that will take decisions autonomously based on collections of big data without any human beings "in the loop". Moreover, the patterns extracted from big data for use in decision making do not need to exhibit Michie's "human window", i.e. the requirement that such patterns should be plausible to a human domain expert. What is at stake can be illustrated by considering the legal, ethical, and societal implications of driverless cars and future unmanned combat air vehicles.

It seems likely that the development of driverless cars has progressed so far that they will soon be approved for everyday use by ordinary members of the public. When that happens, the occupants of a driverless car will no longer need to include someone who has a driving licence. To take the example further, partygoers will no longer need to ensure that one of their party remains sober, so long as they take a driverless car home. At the legal level, laws against drinking while driving will have to be modified.

The societal issues will be more far-reaching. At the time of writing, taxi drivers in several countries are protesting against the recent introduction of the Uber app, which allows drivers and passengers to share rides, on the grounds that the app takes their business away. However, taxi drivers seem unaware of the effect that driverless cars will have on their jobs. The profession of taxi driver is likely to vanish entirely, if passengers can simply call up a driverless car whenever and wherever needed. In a decade or two, taxi, bus, and truck drivers may well all be a faint memory, just as the typing pool now is and CD- and book-shop personnel soon will be.

Existing unmanned combat air vehicles (UCAVs) are tele-operated. This means that they are steered remotely by a human pilot, connected by high-bandwidth telecommunications, usually transmitted via satellites. If a UCAV drops a bomb, then this is the result of the pilot's decision. A human can be held responsible for the consequences. By contrast, if UCAVs become autonomous, there will no longer be a human in the loop. If the on-board decision-making function chooses to drop a bomb on a wedding party or a neutral embassy building, then who is responsible? The UCAV's operator? Its manufacturer? The programmer of the decision-making software? And if software algorithm employs pattern-matching from big data, should the database administrator be held responsible? Or the researcher who specified the algorithm? The graduate of an AI bachelor or master programme may very well be confronted with such issues.

These two examples have shown that, while the KION frame of reference includes the data mining and autonomous systems topics, there are legal, ethical and societal issues that do not appear to be adequately covered. Some universities may include such issues in other topics, e.g. in the Philosophy of AI, but this is not a clear requirement in the KION document. We recommend that the KION document should be modified to explicitly include legal, ethical, and societal issues, either as a separate topic or included in an existing topic.

Trends (3) to (7) can be addressed more briefly. Sensor networks (trend 3) are being introduced in public areas, such as railway stations and airports, to spot criminal and terrorist behaviour. For example, a smart camera can spot people who misuse vending machines, a group of people fighting, or a pickpocket in action. When such behaviour is identified, the camera can alert the authorities, while switching on other sensors (e.g. microphones, other cameras) to capture additional information. Along the road network, cameras can follow a vehicle (e.g. a stolen car), with one camera triggering the next according to the direction in which the vehicle is travelling. This was done manually with great effort after the event in the case of the London bombings, but can now be done in real time.

Humans and robots currently operate separately from one another. Robots are generally tele-operated by a human operator, as described above for UCAVs. However, in the space and defence worlds, user organizations are looking forward to humans and robots working together as a team (trend 4). This brings with it new research issues in human-machine interaction, especially where the robots have a degree of autonomy. Not only will the human need to understand what the robot is doing, but also the robot will need to understand the human's line of thinking. In particular, since humans are known to be driven to a large extent by emotions, robots will need to be able to detect and reason about human emotions. This is known as affective computing (trend 5).

Multi-agent systems is already a core topic in the existing KION frame of reference. However, this tends to be treated from a technical point of view. There is extensive work in the social sciences on applying multi-agent systems techniques to simulate how groups of people, communities, and whole societies interact with one another, e.g. in economic markets, in the emergence of tribal societies, and in the evolution and spread of cultural traits (trend 6). Application of multi-agent systems techniques in the social sciences is known as agent-based modelling (ABM). A well-regarded scientific journal in the ABM area is the open-access Journal of Artificial Societies and Social Simulation (JASSS), now in its seventeenth volume[16].

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[16] See http://jasss.soc.surrey.ac.uk/JASSS.html (1 December 2014).

Finally, trend 7 is a technical trend. Increasingly, AI programming can be done using solvers, rather than programming an AI algorithm from scratch. In particular, scheduling solvers are commercially available (e.g. the products from ILOG). Solvers should be included in the Programming support topic.

## 5.2 How

In the recent pedagogical-didactic literature we observe a paradigm shift from a description of the content of learning and curriculum development to a description of the teaching-learning process. The emerging technology of social media enables open and online learning on a large scale. The Massive Open Online Courses (MOOCs) attract thousands of students and social media link students and educational material together. In "classical" learning or e-learning students have access to learning material remote in place and time. Students are involved in individual self-study activities. The introduction of social media in the teaching/learning process transforms the individual learning process in a group learning process. Students are nowadays network oriented. Reading textbooks has been replaced by consulting relevant sites on Internet. The group of teachers/lecturers is also changing. At secondary school we observe that the "teacher new style" is now cooperating with colleagues. They develop new learning material and have discussions how to teach the new material and organise the examination. At universities we observe similar trends. We now present some developments in more detail.

Recently, the Dutch Ministry of Education, Culture and Science (OCW) published a report (Wetenschapsvisie 2025), which included the following statements:

- Staff members with a permanent contract will be more involved in teaching and research. Education will play a more important role in the yearly evaluation of those staff members. An educational career should be better rewarded.
- Exchange of knowledge, application of knowledge, involvement of teachers in recent scientific developments get a high priority.
- The writers of the report are highly charmed by the educational system of Sweden with a focus on lifelong learning, e.g. including courses to update alumni.

Many of these topics are discussed in this report. We observed and stress again that many AI programmes already started with the implementation of these ideas. But there is still room for improvement and the following changes can be expected.

### 5.2.1 New didactic models

In Figure 4 we display our didactic model based on the use of social media in open and online learning. The focus is on communication and cooperation of e-learners. So we assume that the different components are connected and integrated in an e-learning environment via a social media framework. In designing the learning modules the lecturer can choose different didactic methods and models such as web lectures, autonomous learning, practicals, case studies, simulations, reading scientific literature, posing scientific questions, defining problems, problem solving, cooperative learning to model the teaching learning process. All these methods are well known, used in many e-learning courses or classroom courses, and they facilitate a certain modality of learning. Innovative teaching technology has been described in the popular book "Teach like a champion" of Doug Lemov. In his book he reserves a central place for teachers. He stresses the bottom approach of teaching innovations instead of the top down approach by the Board of the school.

But as stated before, the innovative aspect of our perspective on didactics is a social network of cooperating "study-friends". They communicate with each other by sending tweets, information on Facebook or WhatsApp. As shown in Figure 4, there is a cloud of connecting, interacting students distributed over a huge (worldwide) area. In principle every interested student can have access to the open network and no entrance exams are required. It is assumed that the network filters out students with the expected abilities, motivation and study involvement. Lecturers play a minor role in the learning networks. But they have a leading role at the start up of these new types of courses. An interesting aspect in Figure 4 is that there is also a cloud of connecting, interacting lecturers based on social media or classical e-mails. It can be expected that over the coming years there will be more cooperation between lecturers in the AI community in the Netherlands. We recommend a society of AI lecturers as a section in the BNAIC community.

### 5.2.2 Similar trends in research and education

The last decennia we observed a revolution in the research community. For many years researchers were involved in individual research. Regularly at conferences and workshops they presented their recent scientific results and wrote papers in Journals. There were famous examples of researchers working for years in splendid isolation. Nowadays networking is the buzzword. National or European research proposals are based on joint research activities. Proposals with planned research activities and to be expected deliverables, ordered in Work Packages and time schedules are submitted by a group of researchers distributed over universities and countries. In parallel we observe a similar process in business communities. Local companies are fused to worldwide enterprises. From people involved in this business it is expected that they have excellent networking abilities. From universities as educational Institutes maybe expected that they take a leading role in this process. Opponents may argue that paradigm shifts in the process of teaching-learning take a long time. That is definitely true, but recent developments around MOOCs prove the opposite in this particular case. Maybe the reason is that excellent lecturers and excellent Institutes and universities take the lead.

### 5.2.3 MOOCs

Development of MOOCs is no longer business of some universities. On 17 November 2014 OCW and Surf started a call for project proposals for open and online learning. There is yearly budget available for the period 2015-2018. There is also a call for project proposals for research in open and online education for cooperating educational institutes. These calls provide an opportunity for the AI community in the Netherlands to start common activities on MOOCs development

An interesting aspect of MOOCs is that part of the educational material can be used as modules in blended learning. We discussed already the option to develop a joint e-learning AI curriculum for the Netherlands. All AI partners can offer the whole curriculum or part of it to their students. Developing educational material is a time consuming process which requires many man-hours and expertise. For that reason we propose an educational network of AI involved lecturers. One of the AI partners should take the lead.

Coursera, edX and Udacity are consortia of international excellent universities focussed on the development and distribution of MOOCs. They provide courses that may be of interest to Dutch AI students. Sebastian Thrun developed an excellent AI course distributed via Coursera. It turns out that only a fraction of registered students finished the course. Blended courses show promising results. Students with an academic degree profit more from

MOOCs. MOOCs offer great opportunities for "lifelong learning". An interesting option is to develop a common MOOC (or set of MOOCs) for the AI community. We challenge Dutch AI programmes to focus on developing MOOCs of their own. Traditional courses can be transformed to MOOCs. But the development of corresponding didactic models is lagging behind. Most AI lecturers are involved in AI research and less in didactic research. But all involved universities have a central service of educational experts. Developing appropriate didactic models underlying MOOCs is a matter of joint research of AI lecturers and educational experts.

### 5.2.4 AI as an educational task

An academic study is supposed to provide a basis for lifelong learning. Training students as a scientist provides them the knowledge and abilities to increase/adapt/apply their knowledge. Additional research is needed to validate this hypothesis. Industry continuously complains that students are only educated as scientists. So universities have to show that students are also adequately prepared for occupations outside academia. It may be expected that universities put more effort in alumni networks. Social media again provide a challenging opportunity. An interesting question is how to integrate mechanisms in the curricula such that that they optimally adapt to new developments. As defined in 2.4 of the KION frame of reference students, staff and curricula have to anticipate on continuous change.

It is a long debate whether the task of universities is to transfer academic knowledge or also to contribute to students' personal development. AI topics as robotics, artificial life, agents, intelligence are strongly linked with philosophical, psychological and ethical themes. AI provides the opportunity to educate students not only as scientist but also as human beings. The integration of topics from psychology and philosophy should be used in the education of students as human beings.

# 6. Conclusions & Recommendations

*In this section, we summarize the report, draw conclusions, identify the report's contributions and limitations, and make recommendations.*

## 6.1 Conclusions

The main goal of this report was to research what is lectured in AI courses and how it is lectured. All six participating universities with AI curricula defined their own specific curricula. But all universities agreed upon the KION, the frame of reference which was assumed to be the basis of all individual curricula. In their critical reflections, the universities showed that they satisfied all the requirements to be called AI curricula. With an eye to the future, the question is how up-to-date is the KION report and as a consequence the curricula? The main goal of the report is to provide a critical reflection. This report could be a basis for discussion on possible adjustments of the KION standard. Our report also provides some insight in the individual curricula. We stress the fact that the goal of this report is not to perform an additional evaluation of the AI curricula. Our report reflected on the set of curricula as a whole. To support our arguments we studied national and international AI related sources and illustrate our report with examples of the individual "Critical Reflections".

To structure our research, we defined two top-level research questions in Section 1.3:

- RQ 1 (the "what" question): To what extent does the KION frame of reference reflect the international consensus on the definition of and the topics covered by the field of AI?
- RQ 2 (the "how" question): How well do the Dutch bachelor and master programmes on AI, considered as a whole, make use of the latest insights into educational vision, curriculum design, didactic methods, and the professionalization of lecturers?

Next, we provide answers to these research questions (for details see Section 3):

- RQ 1.0: What is the international consensus on the definition of AI?

  We addressed RQ 1.0 in Section 2.2. The definition of artificial intelligence has changed little since McCarthy defined it in 1955 as "the science and engineering of making intelligent machines". While several definitions regard AI as a part of computer science, it is put the computing sciences and the cognitive sciences on an equal footing. In 1980 Nilsson argued for a science of intelligence focusing on intelligent behaviour, whether this is in artificial or natural systems. Modern definitions, such as that of Russell and Norvig (2010) emphasize the role of agency, in which an intelligent system is capable of perceiving and acting on its environment. The only aspect that is perhaps lacking from these definitions is intelligent behaviour – possibly emergent – arising from social interaction between agents, such as communication, collaboration, negotiation, and competition.

- RQ 1.1: What is the international consensus on the sub-fields/topics within AI?

  We addressed RQ 1.1 in Section 2.3 and Appendix D. By comparing a variety of source materials, we identified a set of AI features, categorized into:
  - Functionalities, comprising natural language processing, vision, knowledge representation, reasoning, planning, learning, and robotics. These correspond to the possible functions of a single agent.

- Techniques, comprising search, logic, neural networks, evolutionary computing, Bayesian nets, probabilistic techniques, classifiers, control theory, constraint processing, and intelligent interfaces.
- Other features, such as AI tools, multi-agent systems, web & AI, and the philosophy and history of AI.

In addition, there is a wide range of AI applications.

- RQ 1.2: What is the relationship between AI and the wider fields of computer science and cognitive science, together with their reference disciplines?

  We addressed RQ 1.2 in Section 2.4. The relations between AI and the computing and cognitive sciences can be viewed in terms of the flows of knowledge between them. The biological metaphor is balanced by the computational metaphor, and the engineering approach by the cognitive science approach.

  The relationship between AI and computer science is well documented in CS2013. AI also needs to draw on the computer engineering and software engineering disciplines for designing hardware and software for intelligent systems. Likewise, the organizational implications arising from operating intelligent systems can be gained from the information systems discipline, with their maintenance drawing on the information technology discipline. Each of these computing sciences disciplines also has its own reference disciplines, from mathematics, through electrical and electronic engineering, to the organizational and management sciences.

  In the cognitive sciences, AI may draw upon knowledge from psychology, neuroscience, linguistics, anthropology, the social sciences, and philosophy. Unfortunately, the relationship between AI and the cognitive sciences is not well documented. There are different flavours of AI, depending on which of the cognitive sciences is dominant in the Departments and Faculties involved. This diversity should be welcomed.

- RQ 1.3: Does the KION definition of AI reflect the international consensus on the definition of AI?

  We addressed RQ 1.3 in Section 3.1. The KION frame of reference defines AI as "the study of intelligence, whether artificial or natural, by computational means" (section 1, p.3). This definition fits well with the international consensus.

- RQ 1.4: Does KION identify a set of topics for AI bachelor and master programmes that is compatible with the international consensus on the sub-fields/topics for AI study and research?

  We addressed RQ 1.4 in Section 3.2. The KION frame of reference identifies a set of topics for AI bachelor programmes. It is less clear on topics for AI masters. The topics are divided into core and elective courses/modules, with the core being further split into AI and supporting topics. We found that the KION topics could be readily mapped to the AI functionalities, techniques, and other topics we had identified in the international literature. There were some differences, including:
  - KION's omissions. Search, planning and scheduling, and decision making are the key omissions in the KION document. Among the supporting topics, we miss information theory, communications theory, and network science /

graph theory. These omissions all need to be rectified when the KION document is next updated.

  - KION's extras. Modules and courses mentioned in the KION frame of reference but not in the international literature are led by autonomous systems. Many are AI applications (e.g. data mining, information retrieval, virtual reality & gaming, and bio-informatics). Others are related to the cognitive sciences, with psychology, neuroscience, and linguistics being represented, but not anthropology or the social sciences.

- RQ 1.5: Does the KION frame of reference detail the content of the AI topics, e.g. in the form of learning outcomes?

  We addressed RQ 1.5 in Section 3.3. A key weakness of the KION frame of reference is that topics are just named. They are not defined, even though workable first-cut definitions can be found for most topics from (e.g.) Wikipedia. Moreover, the topics are not described or detailed in any way. We recommend that the topics should all be defined and detailed in terms of sub-topics and learning outcomes, similar to CS2013.

- RQ 1.6: Does the KION frame of reference give any guidelines on educational aspects, such as the educational vision, curriculum design, didactic methods, and/or the professionalization of lecturers specific to AI bachelor and master programmes?

  We addressed RQ 1.6 in Section 3.4. The KION frame of reference gives limited guidance on educational aspects. Its educational vision is that an AI degree should enable graduates to cope with and even benefit from the rapid change that is a continuing feature of the field. The assumption is that, after graduation, they will do research, whether this is in the academic or commercial worlds. There is some material on the qualification required of lecturers. There is no advice in the KION document on curriculum design or didactic methods.

- RQ 2.0: What are the latest insights into educational vision, curriculum design, didactic methods, and/or the professionalization of lecturers at bachelor and master levels?

  In this report, we stressed the idea of a community of learners. In such a community, there is a place for individual learners, but they are supposed to cooperate and communicate with one another, as well as with the lecturers. The challenge is to transform the community of "friends" into a community of "learners". One possibility is to use social media to enable social learning.

- RQ 2.1: To what extent are the KION's core and elective AI topics covered by one or more of the Dutch bachelor and master programmes?

  If we take the union of all AI courses in the Netherlands all AI topics as defined in the KION report are covered. But at individual universities there are many gaps. It was agreed by all participating universities that KION should provide a basis and leave room for local adaptation. At individual universities there is a lot of AI expertise available at different Faculties. This enables AI students to combine different expertise. But there exist AI variants which are only loosely connected to AI. There is need to redefine the core of AI topics in KION and all participating universities should agree upon it and implement it in their individual AI curricula.

- RQ 2.2: How well do the Dutch bachelor and master programmes on AI design their curriculum in a uniform way?

  As a first step, universities have to define the goals of the AI lectures, the way to realise that goals, and the intended learning outcomes. All participating universities agree upon the KION frame of reference and adapt it to these general goals. The KION report structures individual programmes in this way. Differences can be observed in the way how the goals are defined and realised in individual courses.

- RQ 2.3: How well do the Dutch bachelor and master programmes on AI define, implement, and evaluate their educational vision in comparison with international best practices?

  How the general educational goals are realised in individual courses and are distributed over the courses is not clear defined. This also holds for the evaluation of the general goals. Learning outcomes are defined for individual courses and assessed by individual exams. The evaluation of the general educational goals is not clearly defined. We may expect that NVAO will define additional guidelines for the coming future.

- RQ 2.4: How well do the Dutch bachelor and master programmes on AI determine the appropriate didactic methods for AI subjects consistent with their educational vision?

  Most universities have a group of educational experts on the central level of the university. They provide help and support to AI Departments. In this report we stressed the fact that most lecturers still use an individually didactic approach inspired by their teaching examples. In the training courses for lecturers, they are stimulated to define their didactic concepts and implementation in an explicit way. The general didactic concepts are mainly defined at the general university level but still not translated to the individual AI courses, with some good exceptions. Cooperation between students in project groups at the university is practised, but cooperation between learners outside the university or even beyond the university is still under development.

- RQ 2.5: How well do the Dutch bachelor and master programmes on AI ensure the continuing professionalization of their lecturers consistent with their didactic methods?

  Thanks to the availability of suitable training courses, lecturers have a growing awareness about their didactic approach. But the main focus of lecturers is still on what to be lectured, and not on how it should be lectured.

- RQ 2.6: How well do the Dutch bachelor and master programmes on AI organize their teaching and learning processes?

  We observed that many employees are involved in the organisation of the teaching process at a professional level. The organisation of the learning process is still under consideration. There is some focus on time management of students, to encourage students to realise the supposed learning hours from the very beginning of a course.

But in most cases this is an individual effort. Using peer students as stimulus or role model is under development.

## 6.2 Recommendations

The KION framework of reference provides a common basis for all AI curricula in the Netherlands. All participating AI programmes have to agree upon it. We recommend updating the current version of KION as follows:

1. Add several missing topics to the common core for bachelor programmes, both in AI (e.g. search, planning and scheduling, and decision making) and in supporting disciplines (e.g. information theory, communications theory, and network science);
2. Give operational specifications of the topics mentioned (definitions, intended learning outcomes, and recommended ECs);
3. The current general educational guidelines should be translated into operational guidelines with regard to possible didactic and educational models and their translation into the curricula;
4. Rethink the current guidelines for master programmes. Either choose more detailed guidelines to create more uniform, recognizable AI programmes, or allow for differentiation based on a minimal definition of the AI character. This definition should at least include models of cognitive processing and/or implementations of these models;
5. Require bachelor and master theses to show how their topic falls within the definition of AI;
6. MOOCs can be a valuable tool to ensure a proper coverage of the (updated) common core for the bachelor programmes, as well as an instrument to stimulate national collaboration and international visibility;
7. The common core in bachelor programmes should not just be a list of topics offered within the programmes, but should be a common basis for each individual student. Students should at least be enabled to select this core programme;
8. The KION framework of reference can only function as a platform for regular exchange of the what-how aspects of lecturing AI if it is sustained be an active network of AI lecturers/programme directors which regularly meets for discussion;
9. This network could be further supported by a newsletter about the what-how aspects of lecturing AI, and by a special session at the yearly BNIAC (Benelux Conference on Artificial Intelligence).

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# Appendices

# Appendix A Survey of Didactic Concepts

Each of the six participating universities reflected on its didactic concept in the Critical Reflections. The following texts are adaptations of those reflections.

**Maastricht University**

The unique educational concept of Maastricht University is problem-based education (PGO). In the bachelor Knowledge Engineering, this concept is transformed to the PCL concept (Project-Centred Learning). Here the students learn to apply the knowledge they gained in the courses in realistic and challenging projects. In small groups students perform all aspects of medium to large scale projects

**University of Utrecht**

The AI education from the University of Utrecht uses the following didactic concept at the basis of the educational /teaching process. In the bachelor programme students learn the basic abilities enabling them to progress in the master programme. The basic abilities are design and performance of empirical research, programming, proving correctness and completion in formal languages.

**University of Groningen**

The goal of the AI curriculum is to teach in a manner that supports the development of each individual student to an independent, proactive adult who can function in a professional manner within fields related to Artificial Intelligence.

In order to reach this goal we support student development on several levels. Our first goal is to help students develop theoretical as well as practical proficiency at a superior level in the core fields of Artificial Intelligence. We also strive to help students develop into efficient communicators, both in text and speech. Equally important is our commitment to helping students develop key professional competences, including effective project planning, time management tools, good work habits including punctuality and professional presentation, goal setting skills, teamwork experience and leadership abilities.

We believe that these skills are best fostered by treating students as developing professionals from the beginning of their academic studies in the following approach:

- stimulating professional behaviour rather than penalizing unprofessional acts
- level of skill and knowledge is not determined by unchanging cognitive abilities but that proficiency grows with time and effort invested in learning and practicing
- to be aware of the differences between students depending on their study experiences and taking this into account in course planning and execution
- students differ in their prior knowledge and ability on a specific field of study and lecturers take this into account in the way they teach their materials and organize their course
- evaluation of students work must be done in an objective and transparent manner
- the main role of a lecturer is to guide students

**Vrije Universiteit Amsterdam**

The curriculum is set up from a problem-oriented perspective. Different subjects from a number of disciplines are included. To build an effective curriculum, explicit attention has to be paid to integration, analysis and application of the chosen subjects.

The teaching concept of the Department corresponds with the general teaching concept of the university. There is no central pedagogical didactic concept for all Faculties such as PGO (Probleem Gestuurd Onderwijs) or SGO (Student Gericht Onderwijs) only guidelines. VU University sees education as a "community of learners". One of the five characteristic features is that students will become familiar with the culture of research and the practice as academic professionals.

**Radboud University Nijmegen**
The underlying didactic concept of the bachelor programme is SAE (Student Activating Education).

The three guiding principles of SAE are:

- Self-responsibility/increasing self-management and goal directed education
- Cooperative learning including the pre-organized and self-organized form
- Conceptual learning in a challenging learning environment

**University of Amsterdam**
"Learning by doing" and "active learning" are the relevant principles underpinning the teaching and learning in the bachelor programme. The programme provides a well-balanced mixed of knowledge acquisition and knowledge application. The educational design is also inspired by Bloom's taxonomy. Within the cognitive domain, courses and projects in the programme cover at least knowledge, comprehension, application and analysis. The bachelor programme provides students the opportunity to tailor their learning experiences to their own interest, by choosing self-proposed projects, and can use elective courses to further develop their interest.

## Appendix B Members of the Assessment Committee

The committee that assessed the 18 Dutch AI programmes consisted of nine members:

- Prof. drs. dr. L.J.M. (Leon) Rothkrantz (chairman), Associate Professor at Delft University of Technology and Professor of Intelligent Sensor-Systems at the Netherlands Defence Academy; Professor of Man Machine Interaction at the Technical University of Prague;
- Prof. dr. ir. D.K.J. (Dirk) Heylen, Professor of Socially Intelligent Computing, Department of Computer Science at the University of Twente;
- Prof. dr. T. J. (Tim) Grant, Emeritus Professor of Operational ICT & Communications within the Faculty of Military Sciences at the Netherlands Defence Academy (NLDA) and founder/director Retired But Active Researchers (R-BAR);
- Dr. J. (Jimmy) Troost, Director of Thales Research & Technology, Delft;
- Drs. M.J. den Uyl, owner of SMRGroup, Senior Researcher and CEO of VicarVision, Sentient and Parabots;
- Prof. dr. L. (Luc) De Raedt, Research Professor at the Lab for Declarative Languages and Artificial Intelligence at the Department of Computer Science of the KU Leuven;
- Prof. dr. P. (Patrick) de Causmaecker, Professor of Computer Science at KU Leuven, Kortrijk Campus, Belgium, guest professor at KaHo St.-Lieven, Ghent, Belgium, and Head of the CODes research group, coordinator of the interdisciplinary research team itec at KU Leuven, Kortrijk Campus;
- R.H.M. (Rik) Claessens, BSc, student of the master's programme Artificial Intelligence of Maastricht University;
- Y. (Yfke) Dulek, student of the bachelor's programme Artificial Intelligence of Utrecht University.

For each site visit a subcommittee was set up, taking into account any potential conflict of interests, expertise and availability. To ensure consistency within the cluster the chairman, prof. drs. dr. Leon Rothkranz, attended all visits.

The coordinator of the cluster visits for Artificial Intelligence was drs. Hans Wilbrink, QANU staff member. He was also the project leader for the visit to Utrecht University and VU University Amsterdam. During the other site visits, drs. Titia Buising was the project leader. To ensure continuity, both project leaders frequently held consultations. The coordinator was also present at the final meeting of all visits within the cluster.

The State of the Art report was written after all the reports of the individual site visits were finished. Prof. dr. Leon Rothkrantz and prof. dr. Tim Grant wrote a draft version of the report, which was then discussed during a special meeting of the committee on November 6, 2014. The input of the committee was incorporated in a final draft version of the report, which was sent to the Faculties involved with the request to check it for factual inaccuracies. Subsequently, the definitive report was approved and sent to the university Boards. On behalf of QANU, the State of the Art project was coordinated by Kees-Jan van Klaveren MA.

# Appendix C KION Domain Specific Framework of Reference

Frame of reference Bachelor and Master programmes in Artificial Intelligence
The Dutch perspective
January 16, 2013

This document is an update of the 2006 Frame of Reference as developed by the KION[17] task force on Curricula for Artificial Intelligence, which was based on:

- Computing Curricula 2013 Strawman Draft for Computer Science developed by the Joint Task Force on Computing Curricula, IEEE Computer Society and the Association for Computing Machinery[18].
- The Onderwijs- en Examenregelingen (OER) of the bachelor and master programmes in Artificial Intelligence administered by the Dutch Universities.
- Tuning Educational Structures in Europe[19].

## 1 Introduction

This document is an update of the 2006 frame of reference for the Dutch University programmes included in the category Artificial Intelligence of the Dutch register of higher education programmes (CROHO)[20]. This frame of reference defines the fields covered by the term Artificial Intelligence as well as the common goals and final qualifications of these programmes.

Artificial Intelligence is a relatively young field. The birth of Artificial Intelligence research is often dated in 1956, when the founding fathers of AI met at the Dartmouth Conference. The history of teaching Artificial Intelligence as a separate discipline is much shorter still, starting in the Netherlands in the early '90's. Consequently, a frame of reference for Artificial Intelligence is still actively developing both in the national and the international context. This document formulates the current Dutch consensus on a national frame of reference for Artificial Intelligence in the Netherlands.

Intelligence is often defined as the ability to reason with knowledge, to plan and to coordinate, to solve problems, to perceive, to learn and to understand language and ideas. Originally these are typical properties and phenomena associated with the human brain, but they can also be investigated without direct reference to the natural system. Both ways of studying intelligence either can or must use computational modelling. The term Artificial Intelligence as used in this document refers to the study of intelligence, whether artificial or natural, by computational means.

### KION: Artificial Intelligence in the Netherlands

The current Dutch Artificial Intelligence programmes were mostly started in the nineties in an interdisciplinary context. Originally they were known under a variety of names such as Cognitive Science (Cognitiewetenschap), Applied Cognitive Science (Technische Cognitiewetenschap), Knowledge Technology (Kennistechnologie), Cognitive Artificial

17 Kunstmatige Intelligentie Opleidingen Nederland
18 http://www.acm.org/education/ (last visited on November 1st, 2012)
19 http://www.unideusto.org/tuning/ (last visited on November 1st, 2012)
20 Centraal Register Opleidingen Hoger Onderwijs

Intelligence (Cognitieve Kunstmatige Intelligentie) as well as Artificial Intelligence (Kunstmatige Intelligentie).

In 1999, the number of recognized labels in the CROHO was reduced, and the aforementioned study programmes were united under the name *Artificial Intelligence*[21]. Initially, this was an administrative matter that did not influence the content of the curricula. It did mean, however, that from then on cognitive science (as the study of natural intelligence) and artificial intelligence (as a formal approach to intelligence) were shared under the heading of Artificial Intelligence. The abovementioned definition of Artificial Intelligence as the study of natural and/or artificial intelligence by computational means was then agreed upon. The KION (Kunstmatige Intelligentie Opleidingen in Nederland) was formed as a discussion and cooperation platform for the united programmes.

Starting in 2002, all university-level study programmes in the Netherlands were divided into a bachelor and a master phase. KION took this as an opportunity to agree upon a common kernel of subjects that would be constituent of every Dutch Artificial Intelligence bachelor programme, with the aim of advancing an adequate fit of all Dutch bachelor programmes to all Dutch master requirements.

### Aim of this document

Now that the Dutch Artificial Intelligence programmes are coming up for accreditation in 2013, KION feels that the essence of the 2006 Frame of Reference is still valid, but an update is called for. However, this document is not intended purely as a description of the current status quo. Rather, it aims to provide an account of what an Artificial Intelligence programme should provide as a minimum (the communal requirements for every study programme called Artificial Intelligence), and how it can extend this basis to distinguish itself from other Artificial Intelligence programmes.

Agreement among the Dutch Artificial Intelligence programmes upon the contents of this document will advance both the equivalence of these programmes, and the understanding on existing and possible profiles within Artificial Intelligence programmes. Moreover, it is hoped that this document will also be a starting point for setting international standards for Artificial Intelligence programmes that, to our knowledge, do as yet still not exist.

## 2. Programme characteristics

This section describes definitions regarding the build-up of bachelor and master programs.

### Areas, courses, modules, and topics

A bachelor programme in Artificial intelligence is organized hierarchically into three levels. The highest level of the hierarchy is the area, which represents a particular disciplinary subfield. The areas are broken down into smaller divisions called modules, which represent individual thematic units within an area. A module may be implemented as a complete course, be covered in part of a course, or contain elements from several courses. Each module is further subdivided into a set of topics, which are the lowest level of the hierarchy. The modules that implement the particular programme (or curriculum) are together referred as the 'body of knowledge'.

### Core and elective courses

By insisting on a broad consensus in the definition of the core, we hope to keep the core as *small* as possible, giving institutions the freedom to tailor the elective components of the

[21] In Dutch: Kunstmatige Intelligentie

curriculum in ways that meet their individual needs. The core is thus not a complete programme. Because the core is defined as minimal, it does not, by itself, constitute a complete undergraduate curriculum. Every undergraduate programme must include additional elective courses from the body of knowledge. This report does not define what those courses should be, but does enumerate options in terms of modules.

**Assessing the time required to cover a course**

To give readers a sense of the time required to cover a particular course, a metric must be defined that establishes a standard of measurement. No standard measure is recognized throughout the world, but within the European Community agreement has been reached upon a uniform European Credit Transfer System[22] (EC) in which study load is measured in European Credits (ECs). One EC stands for 28 hours of study time and a full year of study is standardized at 60 EC. In this document, we shall use the EC metric as the standard of measurement for study load.

**Coping with change**

An essential requirement of any Artificial Intelligence degree is that it should enable graduates to cope with—and even benefit from—the rapid change that is a continuing feature of the field. But how does one achieve this goal in practice? At one level, the pace of change represents a challenge to academic staff who must continually update courses and equipment. At another level, however, it suggests a shift in pedagogy away from the transmission of specific material, which will quickly become dated, toward modes of instruction that encourage students to acquire knowledge and skills on their own.

Fundamentally, teaching students to cope with change requires instilling in those students an attitude that promotes continued study throughout a career. To this end, an Artificial Intelligence curriculum must strive to meet the following challenges:

- Adopt a teaching methodology that emphasizes learning as opposed to teaching, with students continually being challenged to think independently.
- Assign challenging and imaginative exercises that encourage student initiative.
- Present a sound framework with appropriate theory that ensures that the education is sustainable.
- Ensure that equipment and teaching materials remain up to date.
- Make students aware of information resources and appropriate strategies for staying current in the field.
- Encourage cooperative learning and the use of communication technologies to promote group interaction.
- Convince students of the need for continuing professional development to promote lifelong learning.

## 3. Shared identity

**Common role**

Apart from the roles academics usually perform in society students of Artificial Intelligence are educated to enrich society with the benefits a formalization of intelligence and intelligent phenomena can provide. In particular this entails that an alumnus of Artificial Intelligence can contribute to the understanding and exploitation of natural and artificial intelligence. This

22 http://ec.europa.eu/comm/education/programmes/socrates/ects/index_en.html (last visited on September 1st, 2012)

may lead to new technologies but it may also enrich designs, products, and services with intelligence so that they are more effective, more reliable, more efficient, safer, and often require less natural resources. This role, in combination with the interdisciplinary nature of the field, requires the Artificial Intelligence alumnus to be able to contribute to interdisciplinary teams and, in many cases function as an intermediate who facilitates the interaction of (other) domain specialists.

**Common requirements**

Artificial Intelligence is a broad discipline and many approaches to the study of intelligent phenomena are justified and fruitful. Curricula are therefore often different from their siblings in emphasis, goals, and capabilities of their graduates. Yet they have much in common. Any reputable Artificial Intelligence program should include each of the following aspects:

- Essential and foundational underpinnings of the core aspects of intelligence. These must be founded on empirical efforts and based on a formal theory, and they may address professional values and principles. Regardless of their form or focus, the underpinnings must highlight those essential aspects of the discipline that remain unaltered in the face of technological change. The discipline's foundation provides a touchstone that transcends time and circumstances, giving a sense of permanence and stability to its educational mission. Students must have a thorough grounding in that foundation.
- A foundation in the core concepts of modelling and algorithms for implementing intelligence. The construction and use of models (simplified, abstracted and dynamic representations of some phenomenon in reality) is common to many sciences. In Artificial Intelligence, however, model building is central: the field of Artificial Intelligence may actually be defined as trying to model aspects of (formal or natural) intelligence and knowledge. Moreover, models within Artificial Intelligence have specific characteristic: they are computational and therefore necessarily formal. Artificial Intelligence-graduates must therefore be able to work with (computational) models at different levels of abstraction and understand the recursive nature of models in Artificial Intelligence. This foundation has a number of layers:
    - An understanding of, and appreciation for, many of the diverse aspects of intelligence, models of intelligent phenomena, and of algorithms that describe intelligent processes.
    - Skills to model intelligent phenomena and appreciate the abilities and limitation of these models, if appropriate in comparison with a natural example.
    - Skills to model and implement intelligent phenomena on a computer, in particular skills to work with algorithms and data-structures in software.
    - Skills to design and build systems that are robust, reliable, and appropriate for their intended audience.
- An understanding of the possibilities and limitations of what intelligent systems can and cannot do. This foundation has a number of levels:
    - An understanding of what current state-of-the-art can and cannot accomplish, if appropriate in combination with the accomplishment of the natural system that inspired it;
    - An understanding of the limitations of intelligent systems, including the difference between what they are inherently incapable of doing versus what may be accomplished via future science and technology;
    - The impact of deploying technological solutions and interventions on individuals, organizations, and society.

- The identification and acquisition of non-technical skills, including interpersonal communication skills, team skills, and management skills as appropriate to the discipline. To have value, learning experiences must build such skills (not just convey that they are important) and teach skills that are transferable to new situations.
- Exposure to an appropriate range of applications and case studies that connect theory and skills learned in academia to real-world occurrences to explicate their relevance and utility.
- Attention to professional, legal and ethical issues such that students acquire, develop and demonstrate attitudes and priorities that honour, protect, and enhance the profession's ethical stature and standing.
- Demonstration that each student has integrated the various elements of the undergraduate experience by undertaking, completing, and presenting a capstone project.

## Shared background for bachelor programmes

Similar to alumni of programmes such as Physics, Computer Science, and Psychology, all Artificial Intelligence bachelors are expected to share a certain amount of support knowledge, domain specific knowledge, specialized domain knowledge, and a set of skills. The content mentioned below ensures a firm common basis that enables AI bachelors of any Dutch university admission to any Dutch Master programme in AI. At the same time, it allows for a wide range of individual and/or institute specific specialisation. The list is an update (extension) of the shared programme agreed upon by the KION platform in 2006.

*Common core between AI bachelor degree programmes*

The following topics and skills are part of each of the bachelor programmes, either as a dedicated course or as a substantial topic within one or more courses.

*Artificial Intelligence modules*

- Autonomous systems
- Cognitive psychology
- Computational linguistics
- History of Artificial Intelligence
- Human-computer interaction
- Knowledge representation and reasoning
- Machine learning
- Multi-agent systems
- Philosophy for Artificial Intelligence

*Support modules*

- Computer science
  - Programming
  - Data structures and algorithms
- Logic
- Mathematics
  - Calculus
  - Probability theory
  - Linear algebra
  - Statistics

*Academic skills*
Apart from curriculum specific skills, the bachelor program supports the development of a set of general academic skills. Even though they can be topics in specific modules, they are generally addressed by the appropriate choice of work and assessment methods throughout the curriculum.

- Analytic skills
- Empirical methods
- Modelling
- Teamwork
- Written and oral communication, argumentation and presentation

*Artificial Intelligence elective courses*
The following list of modules is considered as representative of the AI field at this moment. Given that the different AI programs have different priorities in selecting topics, and assigning topics to either the Bachelor or Master, each Bachelor should offer a substantial subset of the following list as part of their Bachelor programme, either as specific course, or as a substantial part of a broader course.

- Cognitive modelling and Architectures of cognition
- Data mining
- Information retrieval
- Language and speech technology
- Neural nets
- Genetic algorithms
- Probabilistic models
- Cognitive and computational neuroscience
- Perception (Computational and Natural)
- Robotics
- Reasoning under uncertainty
- Virtual reality and Gaming
- Web Intelligence
- Bio-informatics

## 4. Bachelor programme Artificial Intelligence
This section is divided into two parts. Section 4.1 describes the roles that a bachelor ought to be able to perform in society. Section 4.2 describes the final qualifications that bachelors in Artificial Intelligence possess in order to fulfil these roles.

### Objectives
The objective of the bachelor programme is to provide students with a suitable basis for a further career, both in education as well as in employment. The bachelor must be prepared for a number of different roles and opportunities.

*Access to master programmes*
The bachelor provides the student with the specific knowledge and abilities, exemplified in the form of a bachelor diploma that allows the bachelor access to a master programme in Artificial Intelligence or other national or international masters, particularly in related disciplines.

*Professional career*
The bachelor prepares for a position in which the student can earn his or her own subsistence. In particular it prepares for:

- Supervised work on a national and international academic level;
- Positions in the modern high-tech society, such as functions in knowledge-intensive companies and knowledge intensive parts of the non-profit sector.

*Academic skills*
The bachelor provides sufficient training in (scientific) reasoning, conduct, and communication to reach internationally accepted standards of academic skills at that level.

*Place in society*
The bachelor programme provides the bachelor with the knowledge and tools needed to form an informed opinion of the meaning and impact of Artificial Intelligence, and an informed notion of the responsibilities of a specialist in this area.

**Final qualifications**
The objectives of the bachelor can be specified into final qualifications. To comply with international standards these qualifications are presented below in terms of the Dublin descriptors for the bachelor's profile[23]. Together these final qualifications must lead to alumni that exemplify the shared identity defined in section 3.

*Knowledge and understanding*
The bachelor demonstrates knowledge and understanding in a field of study that builds upon and supersedes their general secondary education. Knowledge and understanding is typically at a level at which the bachelor, whilst supported by advanced textbooks, is able to include some aspects at the forefront of their field of study.

Qualifications:
- Basic understanding of key areas in Artificial Intelligence in accordance with the shared identity.
- Advanced knowledge of at least one of the key areas in Artificial Intelligence, up to a level that without further requirements grants access to a master programme in this area.
- Knowledge of the symbolic approach to Artificial Intelligence.
- Knowledge of the numerical, non-symbolic, approach to Artificial Intelligence.
- Knowledge of the most important philosophical theories regarding the fundamental questions of AI as well as its ethical, legal and societal implications.
- Knowledge of the most important theories developed in the area of empirical sciences, particularly psychology.
- Expertise in constructing and evaluating computational models of cognitive processes and intelligent systems.

*Applying knowledge and understanding*
Bachelors can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems and/or

[23] http://www.jointquality.org/ (last visited on September 1st, 2012)

designing systems within their field of study. They are able to analyse and model *prototypical* Artificial Intelligence problems by using *known* Artificial Intelligence methods and techniques.

Qualifications:

- The ability to understand, apply, formulate, and validate models from the domains of Artificial Intelligence.
- The ability to apply the symbolic approach to Artificial Intelligence.
- The ability to apply non-symbolic approaches to Artificial Intelligence.
- The ability to design, implement, and evaluate knowledge-intensive.
- The ability to apply tools from mathematics and logic.
- The ability to apply important programming languages used in Artificial Intelligence.
- Analytical approach to problem solving and design:
  - Ability to comprehend (design) problems and abstract their essentials.
  - Ability to construct and develop logical arguments with clear identification of assumptions and conclusions.
- The ability to submit an argument in the exact sciences (or humanities) to critical appraisal.
- Analytical and critical way of thought and ability to apply logical reasoning.
- Openness to interdisciplinary cooperation and ability to effectively participate therein as an academic professional.
- The ability to create an effective project plan for solving a prototypical Artificial Intelligent problem in a supervised context.
- Manage one's own learning and development, including time management and organizational skills.
- The ability to transpose academic knowledge and expertise into (inter)national social, professional and economic contexts.
- Readiness to address new problems in new areas, emerging from scientific and professional fields.

*Making judgements*

The bachelor has the ability to gather and interpret relevant data (typically within the field of study) and to formulate judgements that include reflection on relevant social, academic or ethical issues.

Qualifications:

- Ability to critically review results, arguments and problem statements from accepted perspectives in the field of Artificial Intelligence and neighbouring disciplines.
- Initial competence in search and critical processing of professional literature in Artificial Intelligence.
- Acquaintance with the standards of academic criticism.
- Awareness of, and responsible concerning, the ethical, normative and social consequences of developments in science and technology, particularly resulting from Artificial Intelligence.

*Communication*
The bachelor can communicate information, ideas, problems and solutions to audiences of both domain-specialist and a general audience.

Qualifications:

- Academically appropriate communicative skills; the bachelor can:
  - Communicate ideas effectively in written form and through the use of Information and Communication Technology,
  - Make effective oral presentations, both formally and informally,
  - Understand and offer constructive critiques of the presentations of others.

*Learning skills*
The bachelor has developed those learning skills that are necessary for a successful further study characterised by a high degree of autonomy (typically in the context of a master or a specialist profession).

Qualifications:

- Reflection on one's own style of thought and working methods and readiness to take the necessary corrective action.
- Recognize the need for continued learning throughout a professional career.

## 5. Master programme Artificial Intelligence

This section is divided into two parts. Section 5.1 describes the roles that a master ought to be able to perform in society. Section 5.2 describes the final qualifications that masters in Artificial Intelligence possess in order to fulfil these roles.

### Objectives

The objective of the master programme is to provide students with a suitable basis for a further career, both in research as well as in the rest of society. The master must be prepared for a number of different roles and careers at key positions in society.

*Access to PhD programmes*
The master programme provides the student with the specific knowledge and abilities, exemplified in the form of a master diploma that allows the master access to a PhD programme in a broad range of disciplines, especially in Artificial Intelligence related disciplines.

*Professional career*
The master programme prepares for a position in which the student can earn his or her own subsistence. In particular it prepares for:

- Independent work on an academic level, especially at positions where many of the problems have not been addressed before and where solutions require scientific training
- Key positions in the modern high-tech society, such as higher functions in knowledge-intensive companies and knowledge-intensive parts of the non-profit sector

*Academic skills*
The master programme provides sufficient training in independent scientific reasoning, conduct, and communication to reach internationally accepted standards of academic skills at

that level. Masters can communicate original ideas in their own language and in English to a public of specialists and non-specialists.

*Place in society*
The programme provides the master with the knowledge and tools needed to formulate an informed opinion about the meaning and impact of Artificial Intelligence in society. Masters are able to enrich society with results from contemporary research and oversee the consequences of proposed measures to society and are aware of their responsibility towards society.

**Final qualifications**
The objectives of the master can be specified into final qualifications. To comply with international standards these qualifications are presented below in terms of the Dublin descriptors for the master's profile[24]. Together these final qualifications must lead to alumni that exemplify the shared identity defined in section 3.

*Knowledge and understanding*
The master demonstrates knowledge and understanding in a field of study that builds upon and supersedes their bachelor degree. Knowledge, understanding, and abilities are typically at a level at which the master is able to formulate a feasible research plan in one's own specialisation.

Qualifications:
- Advanced understanding of key areas in Artificial Intelligence.
- Specialist knowledge of at least one of the key areas in Artificial Intelligence, up to a level that the master can appreciate the forefront of research in that field.
- The master is able to judge the quality of his of her work or the work of others from scientific literature.

*Applying knowledge and understanding*
Masters can apply their knowledge and understanding in a manner that indicates a scientific approach to their work or vocation. They are able to handle complex and ill-defined problems for which it is not a priori known if there is an appropriate solution, how to acquire the necessary information to solve the sub-problems involved, and for which there is no standard or reliable route to the solution.

Qualifications:
- The ability to formulate a project plan for an open problem in a field related to Artificial Intelligence in general and the own specialisation in particular.
- The ability to determine the feasibility of a proposal to lead to a solution or design as specified.
- The ability to contribute autonomously and with minimal supervision to an interdisciplinary project team and to profit from the abilities, the knowledge, and the contributions of other team members.
- The ability to choose, apply, formulate, and validate models, theories, hypotheses, and ideas from the domains of Artificial Intelligence.
- The ability to submit an argument in the exact sciences (or humanities) to critical appraisal and to incorporate its essence in the solution of Artificial Intelligence problems.

[24] http://www.jointquality.org/ (last visited on September 1st, 2012)

- The ability to translate academic knowledge and expertise into social, professional, economic, and ethical contexts;
- Awareness of, and responsibility concerning, the ethical, normative and social consequences of developments in science and technology, particularly resulting from original contributions.

*Making judgements*
The master is able to formulate an opinion or course of action on the basis of incomplete, limited and in part unreliable information.

Qualifications:
- Competence in the search and critical processing of all sources of information that help to solve an open and ill-defined problem.
- The ability to demonstrate a professional attitude conform the (international) scientific conduct in Artificial Intelligence.
- The ability to provide and receive academic criticism conform the standards in one specialism of Artificial Intelligence-research.
- The ability to formulate an opinion and to make judgements that include social and ethical responsibilities related to the application of one's own contributions.

*Communication*
The master can communicate information, ideas, problems and solutions to audiences of specialist in (other) research areas and to a general audience.

Qualifications:
- The master has academically appropriate communicative skills; s/he can:
  - Communicate original ideas effectively in written form,
  - Make effective oral presentations, both formally and informally, to a wide range of audiences
  - Understand and offer constructive critiques of the presentations of others.

*Learning skills*
The master has developed those learning skills that are necessary for a successful further career at the highest professional level. The master is able to detect missing knowledge and abilities and to deal with them appropriately.

Qualifications:
- Being able to reflect upon one's competences and knowledge and, if necessary, being able to take the appropriate corrective action.
- The ability to follow current (scientific) developments related to the professional environment.
- Showing an active attitude towards continued learning throughout a professional career.

## 6. International perspective

As stated in the introduction, this frame of reference is intended not only for the Dutch national context, but also to put the Dutch Artificial Intelligence programmes into an international perspective, and possibly to serve as a starting point for an internationally agreed frame of reference. The latter possibility is of course dependent upon international debate and agreement, and at this moment it is not clear how to bring this about, or whether it will in fact be possible. What we can and will do in this document is provide a comparison between the frame of reference as developed in the previous sections and a number of known related study programmes in other countries. In doing this, we hope to show that the developed frame of reference is up to par from an international perspective as well as the Dutch national one.

Having said this, we must immediately recognize that the Dutch national context appears to be rather special in that we only know of specialized bachelor-level Artificial Intelligence study programmes at one university outside the Netherlands, namely at Edinburgh (United Kingdom), which have a rather different programme structure than the Dutch (and general European) one. In our discussion of the Dutch frame of reference in international perspective, we will therefore add to our comparison with the Edinburgh study programme by a comparison with bachelor programmes of study programmes in a related field, notably Cognitive Science. Furthermore, we will compare the Dutch bachelor qualifications with the requirements for enrolment in Artificial Intelligence master programmes in other countries.

A comparison of master programmes is tricky as well. Although, contrary to bachelor programmes, there are several well-known specialized Artificial Intelligence master programmes outside the Netherlands, study programmes at the master level are much more divergent than at the bachelor level. A comparison can therefore only be provided in global, subject-independent, terms.

We have drawn up both the bachelor and master comparisons based on the programme descriptions and course lists received from the involved Universities. However, for the purpose of conciseness, we have left out particular details of the programmes that are largely time-dependent and often change from year to year.

## Comparison of bachelor programmes

*The Artificial Intelligence bachelors in Edinburgh*
Edinburgh University (United Kingdom) offers a range of bachelor degrees related to Artificial Intelligence, one of them in Artificial Intelligence as such, the others in combination with other disciplines (AI & Computer Science, AI & Mathematics, Cognitive Science). An ordinary bachelor degree consists of 3 years, however admittance to the (1-year) master programme can only be obtained by an honours degree, which takes a fourth year of study. In order to compare this system with the European standard of a 3-year bachelor and a 1-2-year master, we will take the honours year of the Edinburgh bachelor programme to be equivalent to the first year of a 2-year master degree in other European countries, and base our comparison of bachelor programmes on the first three years.

*Comparison with the Dutch frame of reference*
It should be pointed out that the (first three years of the) AI related bachelors in Edinburgh show a large variation between them, and an extensive amount of (usually restricted) choices for particular courses within them. In fact, the communality between the Edinburgh Artificial Intelligence bachelors is smaller than communality within the Dutch framework. It seems that the wide variation in Edinburgh Artificial Intelligence related bachelor degrees actually means that the degrees themselves are much more specialized than the Dutch framework proposes, some of them having little or no (cognitive) psychology, others having no mathematics, etcetera. Areas such as philosophy appear not to be obligatory at all.

*The Cognitive Science bachelors in Osnabrück and Linköping*
Both the University of Osnabrück (Germany) and the University of Linköping (Sweden) offer a three-year (180 EC) bachelor's programme in Cognitive Science. The discipline of Cognitive Science is related to Artificial Intelligence, and may in fact be seen as a flavour of Artificial Intelligence, focused somewhat more towards Cognitive Psychology, and somewhat less towards Engineering. The same key knowledge and skills apply in Artificial Intelligence and in Cognitive Science.

*Comparison with the Dutch frame of reference*
Based on studying both programmes, we conclude that the Dutch frame of reference recognizes the same AI-specific areas as both Cognitive Science programmes outside the Netherlands. The Dutch frame of reference devotes as much or more attention to any of these areas as any of those Cognitive Science programmes, with the exception of Cognitive Psychology in Linköping. Moreover, the recognition, in the Dutch frame of reference, that each individual study programme has a specific profile in addition to the communal areas appears to hold for both inspected study programmes outside the Netherlands as well.

## Comparison of master programmes

*Edinburgh*
The Artificial Intelligence master programme in Edinburgh spans a full 12-month period and consists of two parts: taught and research. During the taught part (8 months), lectures, tutorials and group practicals are followed. The research part (4 months) consists of a major individual research project on which a dissertation is written. There is also the option of completing only the taught part, in which case, a Diploma will be awarded. MSc courses in Artificial Intelligence in Edinburgh are grouped in four major areas of specialisation:

- Intelligent robotics
- Knowledge management, representation and reasoning
- Learning from data
- Natural language processing

*Comparison with the Dutch frame of reference*
Comparing the Edinburgh programmes to the Dutch frame of reference, we can draw the following conclusions:

- The main Artificial Intelligence topics that are in the Dutch framework are also represented in the Edinburgh programmes (as shown in the four different identified areas of specialisation).
- The Edinburgh programmes are 1-year, whereas most Dutch Artificial Intelligence master programmes are 2-year programmes. However, the Edinburgh master programme requires a 4-year honours bachelor degree.
- The Edinburgh system knows a 'Diploma' whereas the Dutch system does not. As described above, this Diploma can be awarded after completing only the taught part of the course.
- The Edinburgh programme knows relatively little study load for practical work. Whereas the minimum length of a Dutch master-thesis ('afstudeerproject') is 30 ECs (half a year), the Edinburgh programme has 4 months for doing practical assignments.
- However, the practical work seems to be more research oriented, whereas in the Dutch programme there is also the option to do a final project in industry.

*Stanford*

Stanford has four majors in computer science: Computer Science, Computer System Engineering, Mathematical and Computational Sciences and Symbolic Systems. Symbolic Systems most closely relates to the Artificial Intelligence programmes in the Netherlands. Symbolic Systems is an interdisciplinary program that combines Computer Science, Psychology, Philosophy, and Linguistics in order to better understand cognition in both humans and machines. Viewing people and computers as symbol processors, the Symbolic Systems program explores the ways computers and people reason, perceive, and act. Within the Symbolic Systems major, there is a core set of required classes; beyond this core, students choose an area of concentration in order to gain depth.[25]

*Comparison with the Dutch frame of reference*

Comparing the Stanford study programme to the Dutch frame of reference, we can draw the following conclusions:

- It is surprisingly difficult to find programme objectives, final qualifications etcetera in the available information. This information is mainly of subject-independent, administrative nature. For example "This programme prepares for entering a PhD programme".
- It was already mentioned that there is much variety between the master programmes – both in the Netherlands and abroad. This is also the case for the programmes at Stanford. But still, this variety is on the Computer Science level rather than the Artificial Intelligence level.
- The Stanford programmes seem to have a large freedom in elective courses. In other words, the core of compulsory courses is limited and students have select many elective courses.
- The Dutch framework has more formal subjects (logic etcetera) than the Symbolic Systems programme.

## 7. Concluding remarks

Artificial Intelligence is a developing field. Due to its relatively recent start as a coherent field of research, the term Artificial Intelligence does not have the stature of Physics, Psychology, or even Computer Science. Internationally, the study of natural and artificial intelligence with computational means is firmly, but usually not very visibly, embedded in the fabric of modern Universities.

Modern topics such as gaming, ambient intelligence, ambient awareness, and believable-agent systems are fashionable manifestations of Artificial Intelligence and these and future fashionable spin-offs of Artificial Intelligence will increasingly affect humans. Future challenges will force products, services, and even societies to react faster but remain reliable, to be both flexible and effective, be both efficient and versatile, and to utilize natural resources with maximal benefit. Making the most of this combination of conflicting demands, which is very much at the core of in the concept of *intelligence.*

The Dutch situation is special because of the existence of Artificial Intelligence bachelor and master programs on most of the general universities. This offers the Netherlands a competitive advantage, consistent with its main economic strategy to remain one of the leading "knowledge intensive" economies. This frame of reference explicates how the bachelor and master programmes in Artificial Intelligence of Dutch universities contribute to educate alumni that will take a leading role in meeting these future challenges.

[25] http://symsys.stanford.edu/courses (last visited on September 5th, 2012)

# Appendix D Functions, Techniques and Applications of AI in Literature

| Features | Wikipedia | | AIJ | AI Topics | Nilsson | Bundy | Handbook of AI | Winston | Charniak & McDermott | Rich & Knight | O'Shea & Eisenstadt | Russell & Norvig |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AI | History AI | | | | | | | | | | |
| ***Functionality:*** | | | | | | | | | | | | |
| NLP | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Vision | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| KR | Y | Y | Y | Y | | | Y | Y | Y | Y | | Y |
| Reasoning | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y |
| Planning | Y | Y | Y | | Y | | Y | | Y | Y | Y | Y |
| Learning | Y | Y | Y | Y | | Y | Y | Y | Y | Y | | Y |
| Robotics | Y | Y | Y | Y | Y | | | | | Y | Y | Y |
| | | | | | | | | | | | | |
| ***Technique:*** | | | | | | | | | | | | |
| Search | Y | Y | Y | | Y | | Y | Y | Y | Y | | Y |
| Logic | Y | Y | | | Y | | | Y | Y | Y | | Y |
| NNs | Y | Y | | | | | | | | Y | | |
| GAs | | Y | | | | | | | | | | |
| Bayesian nets | | Y | | | | | | | | | | |
| Probabilistic | Y | | Y | | | | | | Y | Y | | Y |
| Classifiers | Y | | | | | | | | | | | |
| Control theory | Y | | | | | | | Y | | | Y | |
| Constraint processing | | | Y | | | | | | | | | Y |
| Intelligent interfaces | | | Y | | | | | | | | | |
| | | | | | | | | | | | | |
| ***Other feature:*** | | | | | | | | | | | | |
| Tools | Y | | | Y | | | Y | | | | Y | |
| MAS | | | Y | | | | | | | Y | | Y |
| Web & AI | | | | Y | | | | | | | | |
| Philosophy | Y | Y | Y | Y | | | | | | | | |
| History | Y | Y | | Y | | | | | | | | |